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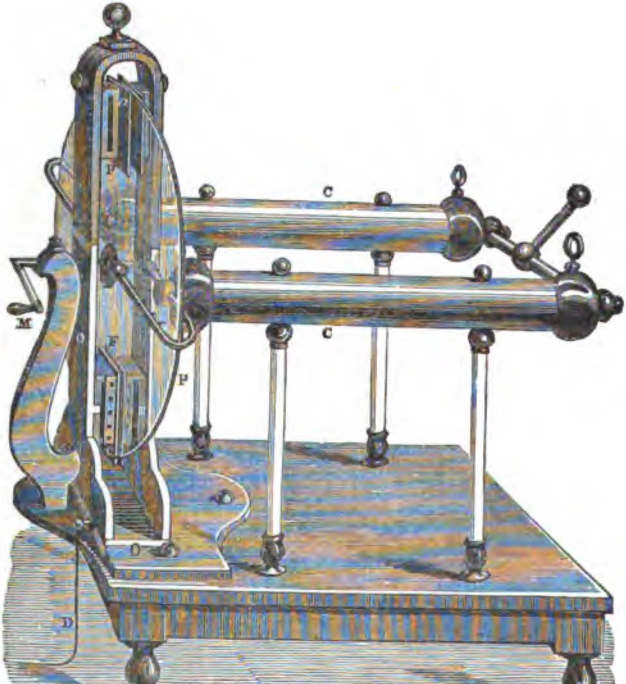

Ramsden's Plate Electrical Machine, (A. D., 1776,) see Sec. 935.

FIRST PRINCIPLES

OF

PHYSICS,

OR

NATURAL PHILOSOPHY,

DESIGNED FOR THE

Use of Schools and Colleges,

BY

BENJAMIN SILLIMAN, Jr., M. A., M. D.

PROFESSOR OF GENERAL AND APPLIED CHEMISTRY IN YALE COLLEGE.

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PREFACE.

THIS hand-book has been prepared with a view to give a fair exposition of the present condition of the several departments of Physics, and to adapt them to the use of those seminaries of learning in the United States in which this subject is taught, without full mathematical demonstrations. Accuracy of statement, fullness of illustration, conciseness of expression, and a record of the latest and most reliable progress of science in these departments, have been the leading objects in its preparation.

Only those who have attempted to harmonize and present in due proportion the whole of so vast a subject as this, in a compendious form, can fully appreciate the labor and difficulties which attend it.

Without claiming for the present volume any credit more than belongs to a faithful digest and compilation from the best authorities in modern science, it is hoped that it will be found suited to the wants of a large class of both teachers and students. No pains have been wanting to secure accuracy both in fact and mechanical execution. The publishers have spared no expense to illustrate the book with a profusion of wood cuts. Many of these are original designs, or are reduced from larger drawings by photography—and others have been selected with care from the best standard authors. It is needless to recapitulate the list of authors whose works have been consulted in the preparation of the text, since the list embraces most of acknowledged repute, both European and American. Whenever it was possible, reference has been had to original memoirs in Journals and Transactions, and in this way many errors current in works of inferior authority have been corrected. With but few exceptions, references to foreign memoirs have been omitted in the text, as their insertion could profit only a very small number of readers, and might seem pedantic. Not so with respect to names of discoverers of important principles and phenomena. A great number of names of these will be found in the text, in their proper places, and not unfrequently the dates of birth, or death, or both, are given.

Every teacher must have observed, in his own experience, that an abstract principle is often fixed in the memory by the power of associated

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ideas, when it is connected with a date, or item of personal interest, as the attention is awakened by the dramatic, far more than by the didactic. Hence it has been thought judicious to introduce numerous important dates in the history of science.

The text is printed in two sorts of type, for the convenience of those who wish to review the chief principles of the science, with its laws, omitting the illustrations and matters of secondary importance. Thus there are in fact two books in one. It has not been possible in all cases to carry out this system rigidly, since, from the great pressure of important subjects, some have unavoiably been thrown into small type which are strictly as important as some others in the larger text. The laws are usually stated in italics.

It gives me great pleasure to acknowledge many obligations to Prof. CHARLES H. PORTER, M. A., M. D., of Albany, (some years my assistant,) for his constant and most important assistance in the compilation and editing of this book. Pre-occupied as my own time has been, I should not at times have found it possible to proceed without his valuable assistance and excellent judgment. Dr. M. C. WHITE, of this town, has also rendered me important aid, especially in OPTICS, and in the revision of the press.

Should this work meet the demands said to exist for such a work as it was designed to be, no care will be wanting to render the succeeding editions entirely free from any errors of the press, or of statement, which may be discovered in this.

NEW HAVEN, CONN., Oct. 15th, 1858.

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FIRST PRINCIPLES

OF

NATURAL PHILOSOPHY OR PHYSICS.

INTRODUCTION.

1. **Our knowledge of the material world** is founded upon experience, or the evidence of our senses, and the conviction that the same causes will always produce the same effects.

By *observation* we become acquainted with those changes in the condition and relations of bodies which occur spontaneously in the ordinary course of nature; but the knowledge thus acquired is meagre and limited when compared with the results of *experiment*. By the use of proper apparatus we can repeat natural phenomena under varied conditions, and, among all the attendant circumstances, we can determine what are accidental, and what are essential to any given effect. In conducting an experiment, we are taught to trace with certainty the *connection* between different phenomena; to classify effects of the same kind and refer them to their common cause; in fine, to *deduce* from many experiments the governing principle, or *law of nature*, in obedience to which they are produced, and to unite both facts and principles into a *theory*, or comprehensive view of the whole subject. Such theories are a fruitful source of new experiments and new discoveries. By a judicious application of their established principles, philosophers have often predicted the results of untried experiments, altogether different from any facts before observed.

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1. Upon what is our knowledge of the material world founded? How should an experiment be conducted? What is meant by inductive philosphy? What is the origin of Inductive Philosophy?

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When individual experience is enlarged by the experience of other inquirers and other times, and the combined knowledge of *many* is so arranged as to be comprehended by *one*, the system becomes a SCIENCE, or philosophy of nature. Because its principles are founded upon a comparison and analysis of facts, a system of this kind is also called *Inductive* Philosophy.

2. **The origin of inductive philosophy** is entirely modern. Galileo (born in 1564) was the first to commence a course of experimental researches; and Bacon (born in 1561) in his immortal work, *Novum Organon*, showed that this was the only road to an accurate knowledge of nature. The ancients were ignorant of the principles and methods of inductive science. Their explanations of natural phenomena were based on *assumed* causes, and they are therefore confused and contradictory, and often in direct opposition to experience.

3. **All material bodies may be distributed into two classes,** viz: *inanimate*, or *unorganized;* and *animate*, or *organized.*

Bodies of the first class, as air, water, minerals, &c., are found in all parts of the earth; they are not endowed with life; they have no definite or periodical duration; and they are acted on only by forces external to themselves.

Organized bodies are individuals, made up of many different organs, each of which is adapted to discharge its own proper functions. They are not everywhere the same, but different *species* belong to different countries. By an innate and peculiar power, called *vitality*, they change inanimate bodies into their own structure, and thus increase in bulk, and provide a succession of individuals like themselves. After a life of definite duration, they die, and their structures dissolve again into the inanimate bodies out of which they grew. They are subject to the general laws of matter, but these laws are often modified, and sometimes directly opposed by the action of that unknown power which we call the *principle of life.* The description of organized bodies constitutes the science of Natural History.

4. **To natural philosophy, or physics,** belongs the inquiry into those general properties of unorganized bodies which we can see, touch, and weigh; into the changes which take place among them, the causes of those changes, and their laws. It investi-

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3. Into what classes may all material bodies be distributed? What is said of unorganized bodies? What of organized? What is Natural History? 4. What subjects of inquiry belong to Physics?

gates also the properties and laws of certain hypothetical fluids or forces, which are without perceptible weight, and the other properties of ordinary matter; these fluids or forces produce the phenomena of Heat, Light, Electricity, and Magnetism.

The phenomena of Physics have this common characteristic; they do *not* result from changes in the nature and constitution of bodies. It is in this that they differ from the phenomena which belong to the domain of chemistry.

All the phenomena of Physics are dependent on a limited number of general laws of which they are the necessary consequences. However various and complex may be the phenomena, their laws are few, and distinguished for their exceeding simplicity. All of them may be represented by numbers and algebraic symbols, and these condensed *formulæ*, enable us to conduct investigations with the certainty and precision of pure mathematics. As in geometry, all the properties of figures are deduced from a few axioms and definitions; so when the general laws of Physics are known, we may deduce from them, by a series of rigorous reasoning, all the phenomena to which they give rise. The most insignificant and the most gigantic effects, sometimes dissimilar and contradictory in appearance, are often produced by the operation of one and the same law.

For example, the *law of gravitation*, the demonstration of which has conferred immortal fame upon Newton, its discoverer, is literally universal in its influence. It pervades every atom, rules alike the motions of animate and inanimate beings, and is as sensible in the gentle descent of the rain-drop as in the torrent of Niagara, or the crash of the avalanche. To the subtle and invisible air it gives the pressure of fifteen pounds upon every square inch of surface, and to the ocean its far greater and almost incredible weight; and, at the same time, it causes the ship to ride the surface of the one, and the feather, or balloon to rise, and the clouds to float buoyantly through the other. By it the lofty structures of man's erection, and the mountains, the mightier architecture of nature, are retained immovably on their foundations.

Its influence transcends the narrow limits of our earth, and ascending the heavens, it not only binds satellites to their

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What common characteristic has this class of phenomena? What is said of the laws of Physics? What may we deduce from these?

planets, and planets to the sun in unchangeable orbits, but it connects sun with sun throughout the whole extent of creation, and is hurrying our solar system with inconceivable swiftness, through an orbit whose period and centre are measureless and unknown. It causes the disturbances as well as the order of nature; since every tremor, which the planets excite in each other by their mutual attraction, changing as their distance changes, is immediately transmitted to the furthest limits of the system, in oscillations, whose periods correspond to their mighty cause.

Like other natural laws, the law of gravitation interprets itself; its operations furnish the means of testing and verifying its own truth. Le Verrier's masterly analysis of the perturbations of Uranus, a planet eighteen hundred millions of miles from the sun, enabled him to calculate and predict not merely the existence, but the mass, period, and position of a new planet, which no mortal eye had ever recognized, and which revolved about the sun at almost twice the distance of Uranus. The confirmation of a prediction so magnificent, while it gave to the law of gravitation the stamp of undeniable truth, seemed to confer upon the intellect of man an almost divine grasp.

5. **The general laws and properties of matter** are not only in themselves attractive and objects of profound interest, but a knowledge of them is a preliminary and essential step to the study of every other department of science; an acquaintance with them is of practical value for everyday business and household uses. No art or trade can be conducted without constant reference to the principles of Physics. Its facts are drawn from the experience of ordinary life, connected into a more orderly and scientific arrangement. Its methods of research are identical with those employed by thinking men in every calling; and its principles are the principles of common sense.

What is said of gravitation? Give the illustrations named in the text. 5. What value have the general laws of matter?

THE PHYSICS OF PONDERABLE BODIES.

General Properties of Matter.

6. **Matter.**—Our senses bear testimony to the existence of matter in a manner too emphatic and self-evident to admit of discussion. Matter is either simple or compound.

7. **Elements.**—Elements, or simple substances, are those which have resisted all attempts by chemical or other means to reduce them to more simple forms; for example, gold and other metals, carbon, sulphur and phosphorous are such substances.

According to our present knowledge there are 62 elements, but it is not at all improbable that the number may increase or diminish as our means of analysis and decomposition are enlarged.

8. **Compounds.**—Compounds are combinations of two or more elements with each other. Although the number of elements is comparatively small, yet the compounds which may result from their combination with each other are innumerable.

9. **Indestructibility of matter.**—Human agency can cause the atoms of matter to pass from one state, or combination, into another; but to destroy them, requires the same infinite power which called them into existence. The various forms of matter may be ground to powder or dissipated in vapor; animals and vegetables may die and be decomposed, their particles may return to the common earth or float invisible in the air, but they are not lost, they enter into an infinite series of new combinations and reappear in other forms of beauty and life. In the ceaseless round of change, the ultimate atoms alone remain unchanged and undestroyed.

10. **Atoms.**—The ultimate constitution of matter has divided the opinions of philosophers from the earliest period of science. Two hypotheses have prevailed; the one, that matter is composed of irregular particles without fixed size or weight, and divisible without limit; the other, that "matter is formed of solid, massy, impenetrable, movable particles, so hard as never to wear or

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6. What is said of matter? 7. What are elements? Give examples. 8. What is said of compounds? 9. Can the atom of matter be destroyed, or only enter into new combinations? 10. What two hypotheses have prevailed in regard to the ultimate constitution of matter?

break in pieces," (Newton,) and which, being wholly indivisible, have a certain *definite* size, figure and weight, which they retain unchangeably through all their various combinations. These ultimate and unchangeable particles are called *atoms*, (meaning that which cannot be subdivided,) or *molecules*, (little masses.)

It is evident that experiment cannot decide between these rival suppositions, for the ultimate particles are far too small to be visible by any means which human ingenuity has yet been able to devise, and they will probably never come within the limits of our direct perceptions.

When we have reduced a mass of matter to the finest impalpable powder, we have made no real approach towards finding its constituent atoms; its minutest particles have the same physical characters as the mass from which they were derived, and of which each is a miniature likeness. Ehrenberg, after exhausting the resources of mechanical contrivance in pulverizing marble, found that its smallest particles were still transparent rhomboids, with angles as perfect as in the finest crystals of calcareous spar.

11. **Form of atoms.**—Two views are now entertained by philosophers as to the form of atoms. The first theory supposes that the crystalline form of a body, (or the form from which it was derived,) is that of its ultimate atoms; for example, a body crystallizing in cubes must, by this assumption, be formed of atoms which are themselves cubes; a body crystallizing in rhombohedrons is formed of atoms which are themselves rhombohedrons, and so on for the atoms of other crystalline forms; this view certainly gives an easy explanation of the crystalline form of simple substances, but there are certain objections to it which prevent its adoption. It does not explain *amorphism*, (bodies destitute of all traces of crystalline form are called amorphous,) nor dimorphism, (bodies crystallizing in two distinct forms are dimorphous.)

The second theory, brought forward by D. Wollaston in 1824, but more fully developed by M. Ampère, supposes each ultimate atom to be a sphere possessed of certain forces of polarity which tend to produce the various forms which crystallized bodies assume. We can easily see how 8 spheres placed together might form a cube, 4 to form the base and 4 immediately above. By a similar mode of arrangement of particles, all the crystalline forms, complicated as they may be, can be pro-

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11. What are the two views of the forms of atoms? Examples.

duced. Great probability attaches to this view; we know the sphere to be the simplest form of matter; it is that form which bodies assume when left more completely to themselves.

The rain drop falling from the cloud, the melted lead from the tower, each assume the form of spheres before reaching the ground; the celestial bodies, it will be remembered, also approach this form.

Although this theory fails to explain why the atoms of different elements when aggregated should arrange themselves in peculiar crystalline forms, yet by it amorphism may be explained, in that the substance being in a viscous condition, the atoms were not free to obey the forces of polarity; or that the substance in a melted state, or in solution, solidifying quickly, the particles did not have time to arrange themselves in regular order, but clustered together without symmetry. Dimorphism might occur when, because of different temperature or from some other cause, the forces that attract the atoms to each other change their position, thus causing the atoms to come together to form crystals different from those usually produced.

12. **Magnitude of atoms.**—A moment's reflection makes it evident that the size of the ultimate atoms of matter must be immeasurably small. The sunbeam discloses countless minute particles of dust floating in the air of the most silent chamber. The perfume of a violet soon fills a large apartment with its delicious odor. A portion of its material substance thus gives evidence to the senses of smell of its diffusion through a great space in particles immeasurably small, and still the flower has lost neither form nor appreciable weight. Nevertheless these are not the ultimate particles (atoms) of matter, but are definite chemical compounds consisting of several elements.

13. **MINUTE DIVISION BY MECHANICAL AND CHEMICAL MEANS.**—Let us, in order to obtain a more precise idea of the wonderful divisibility of matter, refer to some cases of division by mechanical and chemical means. A bar of silver may be gilded and then drawn into wire so fine that the gold, covering a foot of such thread, weighs less than $\frac{1}{6000}$ of a grain. An inch, containing $\frac{1}{72.000}$ of a grain, may be divided

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How is amorphism and dimorphism explained by the second theory? 12. What is said of the magnitude of atoms? 13. Give examples of the divisibility of matter in the silver wire, in Dr. Wollaston's plated wire, &c.

into 100 equal parts distinctly visible, and each containing $\frac{1}{7,500,000}$ of a grain of gold. Under a microscope magnifying 500 times, each of these minute pieces may be again subdivided 500 times, each subdivision having to the eye the same apparent magnitude as before, and the gold on each, with its original lustre, color, and chemical properties unchanged, represents $\frac{1}{3,500,000,000}$ parts of the original quantity.

Dr. Wollaston, by a very ingenious device, obtained platinum wire for the micrometers of telescopes, measuring only $\frac{1}{30,000}$ of an inch in diameter. Though platinum is the heaviest of known bodies, a mile of such wire would weigh only a grain, and 150 strands of it would together form a thread only as thick as a filament of raw silk.

A grain of copper dissolved in nitric acid, to which is afterwards added water of ammonia, will give a decided blue color to 392 cubic inches of water. Now each cubic inch of the water may be divided into a million particles, each distinctly visible under the microscope, and therefore the grain of copper must have been divided into 392 million parts.

One hundred cubic inches of a solution of common salt will be rendered milky by a cube of silver, 0·001 of an inch on each side, dissolved in nitric acid, and the magnitude of each particle of silver thus represents the one hundred billionth part of an inch in size. To aid the student in forming an adequate conception of so vast a number as a billion, it may be added that to count a billion from a clock beating seconds, would require 31·678 years continuous counting, day and night.

14. MINUTE DIVISION IN THE ANIMAL AND VEGETABLE KINGDOMS.—The blood of animals is not a uniform red liquid,' as it appears to the naked eye, but consists of a transparent colorless fluid, in which float an innumerable multitude of red corpuscles, which in animals that suckle their young, are flat circular discs, doubly concave, like the spectacle glasses of near-sighted persons. In man, the diameter of these corpuscles is the 3,500th of an inch, and in the musk-deer, only the 12,000th of an inch, and therefore a drop of human blood, such as would remain suspended from the point of a cambric needle, will contain about 3,000,000 of corpuscles, and about 120,000,000 might float in a similar drop drawn from the musk-deer.

But these instances of the divisibility of matter are far surpassed by the minuteness of animalcules, for whose natural history we are indebted chiefly to the researches of the renowned Prussian naturalist, Ehrenberg. He has shown that there are many species of these creatures, so small that millions together would not equal the

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Give examples from copper and silver. 14. What are the blood corpuscles and their size in different animals?

bulk of a grain of sand, and thousands might swim at once through the eye of a needle. These infinitesimal animals are as well adapted to life as the largest beasts, and their motions display all the phenomena of life, sense and instinct. Their actions are not fluid and fortuitous, but are evidently governed by choice, and directed to gratify their appetites and avoid the dangers of their mimic world. The waters of the globe (and sometimes the atmosphere) everywhere are populous with them, to an extent beyond the power of figures to express, or the imagination to conceive their numbers. Their silicious skeletons are found in a fossil state, forming the entire mass of rocky strata, many feet in thickness and hundreds of square miles in extent. The smooth slate near Bilin, in Bohemia, contains in every cubic inch about 41,000 millions of these animals. Since a cubic inch of this slate weighs 220 grains, there must be in a single grain 187 millions of skeletons, and one of them would therefore weigh about the one 187 millionth of a grain. The city of Richmond, Va., has been shown by Prof. Bailey to rest on a similar deposit of silicious animalcules, of exquisite form. Like larger animals, these animalcules are furnished with organs of digestion and reproduction, and a complex circulating system, whose blood corpuscles are proportioned to the vessels through which they flow. It is impossible to form a conception of the minute dimensions of these organic structures, and yet each separate organ of every animalcule is a compound of several organic substances, each in its turn comprising numberless atoms of carbon, oxygen and hydrogen. It is plain from these examples, that the actual magnitude of the ultimate molecules of any body is something completely beyond the reach equally of our senses to perceive, or of our intellects to comprehend.

15. **Weight of atoms.**—As we can form no precise idea of the absolute size of atoms, neither can we of their absolute weight. But modern chemistry has revealed to us with certainty the *relative weight* of the atoms of the different elements. All chemical compounds have a certain definite constitution; that is, the same compound is always formed of the same elements, and in the same proportion.

Water, for example, is always formed by weight of 1 part hydrogen and 8 parts oxygen.

When a compound is formed, it is supposed that one atom of one element unites with one atom of another, or the union takes

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15. What do we know of the weight of atoms? What of the different constitution of compounds?

place in some other simple proportion as 1 to 2, 2 to 3, &c.; this method of combination being the simplest we can conceive of.

Water, then, is composed of 1 atom of hydrogen and 1 atom of oxygen; but in water the weight of the oxygen is 8 times as great as the weight of the hydrogen; therefore the weight of the oxygen atom must be 8 times as great as the weight of the hydrogen atom.

Chemists have ascertained the proportions by weight in which the various elements combine among themselves, and these proportions are the atomic weights of the elements.

16. **Laws of combination.**—The combination of different elements with each other is regulated by fixed laws. These laws are four in number and every chemical combination is made in accordance with them.

a. *Law of definite proportion.*—In every chemical combination the nature and proportion of its constituent elements are fixed, definite and invariable.

For example: 100 parts of pure water, however produced, contain 11·11 parts hydrogen, and 88·89 parts oxygen. Again, common salt is always composed in 100 parts, of 23·17 parts of the metal sodium, and 60·48 parts chlorine; if now we should mingle these elements in any other proportion than those just stated, the excess of one or the other would remain free and uncombined.

b. *Law of multiple proportions.*—This law requires that when two bodies unite in more proportions than one, these proportions bear some simple relation to each other, as 1 to 1, 1 to 2, &c.

For example: 1 part by weight of hydrogen combines with 8 parts of oxygen and forms water; 1 part of hydrogen also combines with 16 parts of oxygen and forms binoxyd of hydrogen; these proportions of oxygen with hydrogen, it will be observed, bear the simple relation to each other of 1 to 1 and 1 to 2.

In the same manner we may have a series of compounds, as for instance those of nitrogen with oxygen, in which the relation of the atoms of the former is to the latter as 1 to 1, 1 to 2, 1 to

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How do the atoms of different elements unite among themselves? What are the atomic weights of the elements? 16. What are the laws of chemical combination? Their number? What is the law of definite proportion? Example. What is the law of multiple proportions? Example.

3, 1 to 4, and 1 to 5. Again we may have other series of compounds in which the relation, though similar, is not quite so simple; as 2 to 3, 2 to 5, and 2 to 7.

c. *Law of equivalent proportions.*—According to this law, when a body **A**, unites with other bodies **B**, **C**, **D**, the proportions in which **B**, **C** and **D**, unite with **A**, represent in numbers the proportions in which they will unite among themselves, in case such union takes place.

For example: take oxygen, (this element uniting with all others, with the exception of fluorine,) 8 parts of oxygen unite with 1 of hydrogen, 6 of carbon, 16 of sulphur, 28 of iron, 100 of mercury, &c.

The numbers attached to the elements, representing the proportions in which they will unite with each other, are called their *equivalents*, because they represent quantities which are exactly capable of replacing each other in combination.

For example: if we have a compound of 100 of mercury and 8 of oxygen, the 100 of mercury can be replaced by 28 of iron, 16 of sulphur, &c., and also the 16 of sulphur will unite with 28 of iron, and so for other elements.

d. *Law of combining number of compounds.*—According to this law the combining proportion of a compound body is the sum of the combining weights of its several elements. It has just been shown that the equivalents of the several elements are their combining proportions, and it follows as a necessary result, that the proportion in which a compound will unite with another body, or its combining number, is the sum of the equivalents of its constituents.

For example: we wish to know the combining proportion of sulphuric acid; sulphuric acid is composed of 1 atom of sulphur, whose equivalent is 16, and 3 atoms of oxygen, whose equivalent is (3 times 8) 24. 24 and 16 equals 40. 40 is the combining number, or, 1 equivalent of sulphur and 3 equivalents of oxygen, that is of sulphuric acid, and the number 40 is the proportion in which sulphuric acid will unite with other bodies.

What is the relation of the atoms to one another? What is the law of equivalent properties? Example. What is meant by equivalents? Example. What is the law of the combining number of compounds? What is the combining number of sulphuric acid?

The General Properties of Matter.

17. **The physical properties of bodies** are those external signs by which we recognize their existence. They divide themselves into two classes. The *essential* or *principal*, and the *non-essential* or *accessory*. The former are common to all bodies, and inseparable from them. They are the proper and only tests of materiality. Where their presence is not evident to the senses, or cannot be proved to exist, there matter does not exist. Thus, it is essential to the existence of every form of matter that it occupy a certain space, that no other body occupy the same space at the same time, and that it offer a certain resistance to motion, which we call weight. In physics these three properties are named *magnitude*, *impenetrability*, and *gravity*.

1. *Essential Properties.*

18. **Magnitude** is observed to belong to all bodies which are not so minute as to elude the senses, and to such it may be traced by the reason. We cannot conceive of the existence of any particle of matter so minute as not to occupy space.

Magnitude has three dimensions; *length*, *breadth*, and *thickness*. Its external limits are lines and surfaces. Lines are measured by *linear* inches, feet, miles, &c. Length and breadth combined, form a surface, whose area is measured by *square* inches, feet, miles, &c. The quantity of space occupied by a body, called in common language its *size*, is correctly termed its *volume;* and its measurement is expressed in *cubic* inches, feet, miles, &c.

19. **Impenetrability** causes matter to occupy a certain space to the exclusion of all other matter. It is evident that two masses of lead, wood, or any other solid substance, cannot fill the same space at the same time. There are many instances of apparent penetration; but in all these cases, the parts of the body which seem to be penetrated, are only *displaced.*

When a nail is driven into wood, the particles of wood are not divided, but thrust aside. A bullet dropped into a cup of water displaces an amount of the fluid equal to its bulk. Air, which offers

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17. How may the physical properties of bodies be classified? 18. What are the dimensions of magnitude? How are they measured? 19. What is said of impenetrability?

no perceptible resistance to our bodies when walking through it, is really as impenetrable as solids. If an inverted tumbler is sunk into water, the liquid will not fill the apparently void space, because it is already full of air. An important application of this property of air is seen in the diving-bell.

20. **Gravity** is the tendency of bodies to approach the earth and its centre. All bodies, when not supported, fall to the earth's surface; and, if prevented from falling, they exert a pressure that is the measure of their gravity, and which is called weight.

This is one of the most important properties of matter, and the cause of many phenomena which will be fully explained in succeeding chapters.

2. *Non-Essential Properties.*

21. **Non-essential properties.** **Besides the properties already** explained which belong to every individual atom, there are other properties, common to all *aggregate* forms of matter, which are called non-essential, because we can conceive of the existence of matter without them. They are divisibility, compressibility, expansibility, porosity, elasticity, and inertia. There is another group of properties of endless variety, which are found in some bodies and not in others, or in extremely different degrees in different bodies, and which therefore distinguish the *species* of matter and may be called specific; such are ductility, tenacity, color, the attractive power of the lode-stone, &c. They will be explained in their appropriate place.

22. **Divisibility.**—All bodies may be divided into smaller parts, similar to each other and to the entire mass, and these may be again disintegrated, until the particles become so minute as to elude our senses and our instruments. In the arts, the division of matter is carried to an extent which would be incredible, if it were not of daily occurrence, and capable of proof by direct experiment.

23. **Expansibility, and compressibility.**—The same bodies do not always have the same volume, but they may be made to fill a greater or less space without in either instance altering the quantity of matter they contain. Both these changes may be produced in many bodies by mechanical means, and in all bodies they invariably result from the action of heat.

Examples of apparent penetration. 20. What is gravity? 21. What causes the non-essential properties of matter? 22. What is said of divisibility? 23. What is the volume of bodies?

Wires by which heavy weights are suspended are sensibly increased in length. The volume of blank coins and medals is diminished by the stroke of the die. Stone walls are sensibly affected in their dimensions by the daily changes of external temperature.

24. **Porosity.**—Since the atoms of matter are always the same, we can explain the compression and expansion of bodies only by supposing that their atoms are not in immediate contact, but are separated by interstices, which enlarge or diminish as the volume of the body changes. These interstices are called (physical) *pores*, and in this sense *porosity* is a general property of matter. In common language, however, we understand by the term pore, an interstice large enough to admit the passage of liquids and gases. This second and restricted species of porosity, sensible porosity, is not a general property of matter, but accidental, and belongs particularly to certain solids. The *molecular* or physical pores of bodies are permeable only to heat, light and electricity. Almost all animal and vegetable substances present pores which are easily penetrated by fluids.

Petrifactions are produced by the infiltration of mineral substances through the pores of the body.

Many minerals and strata of rocks are porous, and the object of plowing and other similar mechanical operations of agriculture is to increase the natural porosity of the soil.

The metals are not equally porous; but still they are permeable to liquids and gases under great pressure. In 1661, the Academicians of Florence filled a gold sphere with water, and after closing it hermetically, diminished its capacity by pressure; the water traversed the pores of the gold and appeared in the form of dew on the exterior surface.

Faraday found it impossible to make a vessel tight to hydrogen gas even under moderate pressure.

25. **Relation of porosity to weight and density.**—The atoms of different elements are probably of unequal weights, and are placed at variable distances in different bodies; it results from these circumstances that bodies of the same *volume* have not the same *weight*. The weight of a body is always proportional to its *mass;* in other words, to the number of material particles

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Give examples of the change of volume of bodies? 24. What is said of porosity? Of physical and sensible porosity? Examples illustrating porosity. 25. What is the relation of the weight of a body to its mass?

it contains; and the *mass* of a substance is greater as the porosity is less.

The weight of a body is also proportional to its *density*, which expresses the relation of the masses when the volumes are equal. Of several bodies of equal volumes, that which has the greatest *mass* is said to be most *dense*, and therefore has the greatest weight or gravity. As density increases, the pores become fewer and smaller; when they are equally distributed, a body is said to be *uniformly* dense.

A comparison of densities affords a constant, *specific* character to distinguish different substances. The standard of comparison is water; and the number expressing the density, or *specific gravity* of a body indicates, therefore, how much more or less heavy that body is than an equal volume of water. This important subject will be fully explained hereafter.

26. **Elasticity** is that property of bodies which causes them to resume their form and dimensions on the removal of any force by which they have been bent or compressed. This property is found in a high degree in many bodies, and there are none absolutely without it. The *limit* as well as degree of elasticity is very various. If a force is applied exceeding the limit of elasticity, the substance is either torn, or it does not again recover its original form and volume. A description of the modifications of this properly belongs to the history of the substances which display them.

27. **Inertia or inactivity.**—No particle of matter possesses within itself the power of changing its existing state of motion or rest. Matter has no spontaneous tendency either for rest or motion, but is equally susceptible to each, according as it may be acted on by an external cause. If a body is at rest, a force is necessary to put it in motion; and conversely, it cannot change from motion to rest without the agency of some force. A body once put in motion, will continue that motion in an unchanging direction with unchanging velocity, until its course is arrested by external causes. This passive property of matter is called *inertia*.

When we are told that a body at rest will forever remain so, unless it receives an impulse from some external power, the mind

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To its density? What is meant by specific gravity? 26. What is electricity? 27. What is inertia?

at once assents to a statement which embodies the results of our constant experience. But it requires some reflection in one who for the first time considers the subject, to admit that bodies in motion will continue to move forever unless arrested by external forces. Careless observation seems to contradict the assertion. On the earth's surface we know of no motion which does not require force to maintain as well as produce it.

We may observe, however, that all such moving bodies meet with constant obstruction from three forces, friction, gravity and the resistance of the air; and that as one or all of these may be diminished, the motion becomes prolonged and continuous. Besides we have familiar instances of a *tendency* to continue in a state of motion.

The wheel of an engine continues to revolve after the impelling force has ceased; a ball will roll longer and further as the surface on which it rolls is made smoother. When a pail of water is rapidly rotated and suddenly set down, the vessel itself is at that instant brought to a state of rest, but the mobility of the water allows it to continue the motion in its original direction, and it is spilled in consequence of its inertia.

The planets furnish the only example of constant and unresisted motion. These celestial bodies, removed from all the casual resistances and obstructions which disturb our experiments at the earth's surface, roll on in their appointed orbits with faultless regularity, and preserve unchanged the direction and velocity of the motion which they received at their creation.

28. **Inertia proportional to quantity of matter.**—The inertia of a body is proportional to its quantity of matter, and therefore the greater the mass on which a force acts, the greater will be the resistance to either acquiring motion or parting with it. Motion may be continued in a heavy body with a fraction of the force necessary to begin it.

A horse draws with comparative ease a load which at first he had hardly strength to move.

Time is also required to overcome inertia.

What are the obstructions to motion? Give examples of a tendency to continue in motion. 28. What is said of the quantity of matter affecting inertia?

A bullet thrown by the hand will shatter a pane of glass, but shot from a rifle, it will pass through without fracturing it, because there was not sufficient time for the motion of the bullet to be communicated to any part of the glass except that which was immediately before it. A tallow candle discharged from a gun will pass through a board. A small bar of wood, suspended at its ends by two threads, may be broken by a sudden blow in the middle without rupturing the threads. If a coin be placed on a card on the top of a small bottle, or similar support, a sudden impulse, as a snap from the thumb and finger will remove the card, leaving the coin undisturbed.

Inertia is the basis of the whole theory of force and motion, and is the most important general property of matter.

Physical Forces.

29. **Definition of force.**—Since matter is in itself inert, and incapable of spontaneously changing its condition, we are obliged to assign the constant changes which we observe in its relations to the action of some cause included under the general name of FORCE. The idea of *force* is abstract, and like *number*, *space*, *time*, *&c.*, must be referred to the experience or consciousness of each individual. It is difficult and perhaps unnecessary, if not impossible, to give a satisfactory definition of any of them.

Force is the name of the unknown cause of a known effect. We know of the existence of such causes only by their effects, which always appear in connection with something material, and may therefore be recognized by our senses. We can investigate the laws of the motions and equilibrium of forces, but their origin, though perceived to be various, is beyond our comprehension. They are powers conferred upon matter by the will of the Creator, to maintain the order of the world.

30. **Varieties of force.**—Of the forces which act upon bodies, some are accidental and intermittent, as the agency of human and animal strength, and the contrivances of machinery; others act continually upon every kind of matter, and are inseparable from it. To the latter class belong the universal forces of attraction and repulsion.

The approach and retreat of bodies, and of their component

Example. What of time and inertia? Examples. 29. What is said of Force? 30. What of the varieties of force?

parts, is the basis of all the results produced by physical forces. The attraction of matter manifests itself under all circumstances. It is called *universal gravitation*, *gravity*, and *molecular attraction*, according as it is displayed among celestial bodies, among terrestrial bodies, or between the contiguous particles of matter. Because gravitation exerts its influence through a wide extent, and acts at sensible distances, it is also called an *external* force, in distinction from molecular attraction, which, acting only upon the constituent atoms of bodies, and at insensible distances, may be called an *internal* force.

31. **Molecular attraction.**—If the ultimate atoms of matter possessed no property in relation to each other except their mutual impenetrability, the world would be like a mass of sand, without variety of state or form. Atoms, when placed in contact, would neither adhere, as in solids, nor repel each other, as in gases. We find, however, that the particles of solids cannot be separated without the exertion of considerable force, and the effort is so strongly resisted in the metals, for example, that it is much easier to move the whole mass, than to divide it. Consequently there must be a force which holds together the particles of solid bodies in fixed relative positions, and imparts to them an internal structure and an external form. It is assumed that this force is the mutual attraction of atoms, and when it is exerted in uniting the component particles of the *same* body, it is distinguished by the name of *cohesion*.

32. **Cohesion.**—The cohesive attraction of particles in contact is an effort of the same kind as the mutual approach of particles at a distance. The same influence which causes two distant bodies to approach, will hold them together when they are united, and resist their separation. The attractive force which manifests itself at the immense distances between the celestial bodies, and which, at very much smaller distances, produces the weight and mutual attractions of bodies at the earth's surface, aught equally to display itself at all possible distances, however small they may be.

Probably the attraction of masses is only the resultant of the partial attractions of the atoms which compose them; or in other words both gravitation and cohesion are related effects of the same universal cause. We know that the atoms of different elements are of different dimensions and forms, some being sphe-

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rical, while others are spheroidal or ellipsoidal. Again, all bodies may be reduced in bulk by cold and pressure, their atoms are never in actual contact, and the intervals between them, though imperceptible to our senses, are probably very large when compared with the bulk of the atoms themselves. If then, as we may reasonably assume, molecular attraction and gravitation are effects of the same cause, they must obey the same laws, and the intensity of the cohesion of atoms will vary in the direct ratio of their quantity of matter, and in the inverse ratio of the square of their distance.

The variations of molecular attraction, acting according to the above law on atoms of different forms and dimensions, and placed at very variable distances in different elementary and compound bodies, are sufficient to account for all the modifications of cohesive energy which are observed to exist.

33. **The measure of cohesion in solids** is the force required to change their form by flexion or fracture. If this force were not powerful enough to resist the efforts of gravitation, solids would fall to pieces by the weight of their particles. In obedience to cohesive attraction, the movable particles of fluids are drawn around their common centre, and form little spheres, as drops of dew and falling rain.

For the same reason, mercury poured upon paper, collects in small globules in opposition to the gravity of its particles; and liquid lead, poured through the meshes of a sieve, falls through the air in a metallic shower, whose drops solidify in shot during their descent.

34. **Adhesion** is the name given to molecular attraction, when it manifests itself in the adherence of surfaces placed in very close contact. It occurs between the surfaces of the same and different bodies, and between solids, liquids, and gases. Its phenomena, especially those of capillarity, will be discussed in subsequent chapters.

Strictly speaking, there is no phenomenon of adhesion as distinct from cohesion; for in the case of two plates of polished glass, united by a film of oil, it is in reality the force of cohesion between the particles of the oil which holds the plates together. Certain substances are wet by water, while certain others are wet by oil, owing

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What is said of gravitation and cohesion? What of the contact of atoms? 33. What is said of the cohesion of solids? Examples of cohesion in liquids. 34. What is adhesion?

to a species of attraction between the surfaces of the solids and fluids respectively. When, as in the example cited, this wetting occurs, the so called force of adhesion is manifested. Thus glue serves to unite unlike substances, but the union is due to the cohesion in the particles of glue, and not to any attraction between the heterogeneous substances.

35. **Chemical affinity.**—When molecular attraction is exerted between the atoms of different elements, it displays remarkable energy, and forms compound bodies, which possess no property in common with their constituents, except their combined gravity.

When nitric acid is poured upon copper, intense action follows with the evolution of fuming vapors; after the action has ceased, the acid and metal have disappeared, and in their place will be found a beautiful deep blue salt, whose weight and that of the vapors will be equal to the combined weights of the acid and copper. The blue salt is entirely different from either of its ingredients, but if a slip of clean iron is dipped into a solution of it, the copper will be precipitated upon the iron with all its characteristic properties.

36. **Molecular repulsion.**—If a definite volume of air is admitted into a vacuum of twice that capacity, it does not, like a solid or liquid body, retain its original volume, but expands and fills the whole empty space. The same will happen whatever may be the relative volume of the air and the vacuum; in every case the particles of the air will be uniformly distributed throughout the whole void. Since an external force is necessary to hold together the particles of gaseous bodies like air, there must be a force which acts repulsively among their particles; and the same force offers a resistance when their particles are brought together by mechanical pressure. A similar resistance to compression is displayed in liquid and solid bodies. Liquids can scarcely be compressed at all, and they regain their volume when the pressure is removed; the same property is exhibited by all solids in variable degrees of intensity.

37. **Elastic force of heat.**—The mutual repulsion found to prevail among the constituent atoms of bodies is assumed to be due to the *elastic force of heat.* It is certain that the energy of this repulsion is increased or diminished as heat is imparted to bodies or withdrawn from them. Heat produces the same phenomena

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What of its identity with cohesion? 35. What is chemical affinity. Example. 36. What is said of molecular repulsion?

as mechanical compression and expansion, but in a higher degree. Since the accumulation of heat causes the atoms of bodies to separate, and its removal causes them to approach each other, it must be admitted that whatever may be the nature of heat, it acts as a repulsive force. Its repulsive energy is manifested only at very small distances, and between particles of the same body. If we suppose that the atoms of bodies are each surrounded by a highly elastic atmosphere of heat, which modifies the attraction of the molecules, we shall be able to understand how the attractive and repulsive forces proceed from a common centre, and to account for all the observed phenomena, with which this hypothesis perfectly agrees.

38. **Physical states of matter.**—Matter is presented to us in three physical states or conditions, namely: the solid, liquid and gaseous, (æriform or vaporous.) We are familiar with many substances which assume the solid and liquid conditions; most of the metals, for example, in their ordinary state solid, become liquid (melted) when heated. Certain bodies assume either of the three states. Water, for example, liquid at the ordinary temperature, becomes solid (ice) by cold, and vaporous (steam) by heat. And it is the same with many elements. Sulphur, for instance, a solid, by the application of heat, becomes first liquid and upon a continuance of the heat passes off as vapor. Some metals which require the highest temperature of our blast furnaces to melt, and others which even that heat is not sufficient to dispose them to relinquish the solid state, when submitted to the action of the oxyhydrogen blow-pipe or to the heat obtained from the electric pile, immediately liquify, and in a little time vaporize. Of the first class may be mentioned iron; of the second, platinum.

As solids can be made to assume the liquid and gaseous form, so inversely can most gases be converted into liquids and solids by means of intense cold and great pressure. Submitted to their action, carbonic acid, a colorless gas, becomes a clear liquid resembling water, and this liquid allowed partially to evaporate, abstracts so much heat from the remaining portion that the latter becomes solidified; this solid carbonic acid bears an exact resemblance to snow.

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37. What is said of the elastic force of heat? How is heat known to be a repulsive force? 38. What are the three physical states of matter? Mention examples of bodies which may be made to assume the three states? What is said of carbonic acid?

39. **Relations between attraction and repulsion.**—These different states of aggregation result from the definite relations under which molecular attraction and repulsion establish their equilibrium. The excess of the attractive or of the repulsive force will determine whether a body is solid or gaseous, while an equality of both forces produces a liquid. Let A represent the attractive and R the repulsive force, then the three aggregate conditions of matter may be expressed by the following formulæ:

$A>R$, solid
$A<R$, gas
$A=R$, liquid.

In gaseous bodies the particles of matter are more remote from each other than in liquids and solids, and they show a constant tendency to separate. In liquids, the particles approach sufficiently near to produce equilibrium between the attractive and repulsive forces, but not near enough to modify either force by the influence of their form. The particles are at fixed distances in relation to each other, and being similarly attracted on every side, they possess perfect mobility, and offer great resistance to pressure. The distances between the particles of solids are still less, and their relative positions are fixed. The structure of solids is various, because at such small distances, the energy of the mutual attraction of their atoms depends upon their form and dimensions, and is modified by the sides they present to each other during their aggregation.

These three conditions of matter may for the most part be distinguished by their external peculiarities. They are not, however, separated by distinct lines of division, but intermediate conditions are found in infinite variety, corresponding to the various limits at which the two contending forces are balanced. These conditions may be seen in the fusion of metallic and other substances, passing from hardness to toughness, viscidity, &c., to perfect fluidity and even to vapor.

Modified Results of Cohesion.

40. **Modified results of cohesion.**—The various degrees of cohesive attraction in solids give rise to peculiar properties in

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39. What are the relations of attraction and repulsion in the three forms of matter divided by distinct lines?

some of them, or to peculiar modifications of general properties, among which the following may be distinguished; hardness, brittleness, malleability, ductility, and elasticity.

41. **Hardness** has no relation to density, or the number of particles within a given space, but depends only on the mutual arrangement of the particles and the degree of their cohesion.

The metals may be scratched by glass, which is far lighter than most of them, and among metals, density is not connected with relative hardness. Alloys are often harder than either of their constituents, and some metals, as steel, may have their hardness modified by heat at pleasure. The following table gives the scale of hardness used by mineralogists, commencing with *talc*, the softest crystalline solid, and ending with *diamond*, which is esteemed the hardest, since it cuts all other bodies, but cannot be cut by any but itself.

Deg.	Substance.	Deg.	Substance.
1	Talc. . . .	6	Feldspar. .
2	Gypsum. . .	7	Quartz. . .
3	Calc. spar. .	8	Topaz. . .
4	Fluor spar. .	9	Sapphire. .
5	Apatite. . .	10	Diamond. . .

The terms *hard* and *soft* are seen by an inspection of this table, to be entirely relative, since each succeeding body is harder than the one preceding, and vice versa, the extremes only being respectively softer and harder than all others.

We employ hardened steel to cut wood, and even iron; emery, (the rough sapphire,) is required to cut and polish steel and glass; and the diamond, set in a staff of metal for an efficient tool, for cutting plates of glass into any required size. Even the hardest rocks, as porpyhry and jasper, are readily turned into any required form in the lathe, by the use of a diamond properly set as a turning tool.

42. **Brittleness.**—Bodies which are easily broken in pieces and pulverized are said to be *brittle*. Such are hard bodies generally, and many highly elastic substances.

Glass which has been cooled very suddenly is very brittle and

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40. What is said of the modified results of cohesion? 41. What of hardness? What is the scale of hardness? Explain the relative value of the terms hard and soft. 42. What bodies are said to be brittle?

elastic. If the common scientific toy called a Rupert's drop, or Dutch tear—a drop of liquid glass suddenly solidified by dropping it into cold water—is grasped with one hand, and the point snapped, the whole mass will be broken into an almost impalpable powder, with a violent shock.

43. **Malleability**, or the property of being wrought under the hammer, belongs to many of the metals in an eminent degree, and upon it their utility in a great measure depends. It varies according to temperature.

Iron is most malleable when it first attains a white heat, and in that state huge masses of it are taken from the furnace to be forged, the metal yielding like wax to the pressure of the rolling-mill, or the blows of the hammer. Zinc is most malleable at 300° or 400°, and lead and copper when they are cold. Gold may be hammered into leaves so thin that 282,000 of them are only an inch thick. Metals lose their malleability by constant hammering, but recover it again by being heated and slowly cooled—a process called *annealing*.

44. **Ductility**, or the property of being drawn into wire, must not be confounded with malleability, for the same metals are not always both ductile and malleable, or do not possess these properties to an equal extent. In general, ductility increases with the temperature.

Iron may be drawn into the finest wire, but it cannot be rolled into plates of proportional thinness. Tin and lead possess these qualities in the reverse order.

45. **Elasticity**, already mentioned as one of the accessory properties of matter, has a peculiar importance in solids, because it is itself a moving force, and serves to measure the intensity of other forces. All bodies offer a resistance to compression and extension which is the elasticity of the body. It is shown in the sensible effort of a compressed spring or a bent bow, to recover from their forced state of flexion. Elasticity acts in a direction exactly opposite to the compressing force, and in a *perfectly elastic* body is in direct proportion to it. If such a body is compressed to a certain extent by a weight of five pounds, it

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Give examples of brittle substances. 43. What is malleability? What is said of iron and of zinc, &c.? What is annealing? 44. What is ductility? Examples. 45. What is said of elasticity?

will suffer twice that compression by ten pounds; and no matter how long the compression has continued, or how great the alteration of its shape, it will recover its volume and form when the force is removed. There are however no *perfectly* elastic solids; when the applied force is carried beyond the limit of elasticity, it produces either a permanent change of volume, or a fracture.

Highly tempered steel, within certain limits, approaches so nearly to perfect elasticity, that it is in extensive use for spring balances, which weigh accurately enough for ordinary purposes. The reaction of a steel spring is the motive power in watches, door-locks, gun-locks, and various machinery.

46. **Oscillations of elasticity.**—The return of an elastic body to its primitive position is usually made with several oscillations.

If a blade of steel, firmly fixed at one extremity, is bent, it will return to its natural position and pass over it with its acquired velocity, repeating the movement for some time, like the oscillations of a pendulum. It is evident that in bending the steel its molecules are deranged from their position of equilibrium by compression on one side and extension on the other, and that it is the force with which they tend to replace themselves which produces the elasticity of the blade.

There is a similar though less perceptible change of figure in an ivory ball, which, dropped upon marble, will rebound nearly to the height from which it fell. It does not immediately recover its spherical shape, but is for several times alternately an oblate and prolate spheroid.

47. **Elasticity affected by temperature.**—In the arts, great elasticity is produced in certain bodies by a sudden change of temperature. When steel is brought to a high heat and suddenly cooled by immersion in water, it becomes hard, brittle and elastic. It acquires these new properties in a greater degree as the change of temperature has been more considerable and sudden. This process is called *tempering*. The steel may again be made ductile by heating and permitting it to cool slowly. No satisfactory explanation has been given why tempering produces these new properties in steel, nor why it has

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What is said of tempered steel and its uses? 46. How may the oscillations of elasticity be shown? What is said of an ivory ball let fall upon marble? 47. How is great elasticity often produced? What is tempering?

the contrary effect upon other substances. It is certainly accompanied by a rearrangement of the particles, but why this should produce the effects noticed is not so clear.

The alloy, composed of 78 parts copper and 22 tin, of which cymbals are made, by cooling slowly acquires great hardness and elasticity; while tempering, on the contrary, renders it ductile and malleable.

48. **Torsion.**—The elasticity thus far described arises from a force applied lengthwise, and is properly called *flexion ;* but very ductile bodies which are not susceptible of this elasticity, may acquire, in certain circumstances, another kind, which consists of a *lateral* displacement of the opposite sides of a solid in opposite directions, the central particles only remaining undisturbed. This is elasticity of *torsion* or *twisting.* It may be accurately measured by angular displacement, for the angle of torsion is always in exact proportion to the degree of elasticity. On this principle Coulomb constructed his delicate Torsion Balance for the measurement of minute attractive and repulsive forces.

This instrument consists, essentially, of a fine metallic thread, suspended by one end and carrying at the other a horizontal needle of 4 or 5 grains weight, which moves within a graduated circle; and the whole is inclosed in a glass case to protect it from agitation by the air. The angular distance traversed by the needle from the point of departure, measures the intensity of the force communicated to it. This instrument will be more particularly described in the chapter on Electricity.

What is said of the alloy of which cymbals are made? 48. What is torsion? How is torsion measured? Describe Coulomb's Torsion Balance.

CRYSTALLOGRAPHY.

Form and Structure of Solids.

49. **Solid bodies,** as we have already seen, possess a constant volume and an independent form. They are produced by the union of equal atoms maintained at fixed distances, and in *stable* equilibrium by the influence of their mutual attraction and the repulsive force of heat.

The former force greatly preponderates, and consequently the particles of solids cannot move freely among themselves, nor be displaced or separated from the mass without force sufficient to overcome their cohesion. When broken portions are replaced, they no longer show their former cohesion, but only adhesion of their surfaces.

50. **Symmetry of solids.**—Many solid bodies have a perfectly symmetrical form; and in animals, plants and minerals, there exists a tendency of matter, which cannot be mistaken, to combine in complete and symmetrical wholes. The bodies of animals consist, usually, of two equal (or nearly equal) and similar sets of limbs and organs, one on the right and one on the left side. The organs of all flowering plants are similarly and regularly arranged in whorles of *three* members, as in the lily, or of *five*, as in the rose, or in some other simple numbers, and the same law is beautifully exemplified in the arrangement of the leaves and branches of all plants and trees, (*phyllotaxy.*)

51. **Organic and inorganic life.**—In the animal and vegetable world, the laws which direct the aggregation of matter are those of VITALITY, and it is observed that most of the forms thus produced are bounded by curved lines and surfaces. In the inorganic or lifeless world, different laws are in force, and in the production of the solid, the atoms arrange themselves in forms which are angular and bounded by plane surfaces. The geometrical forms thus produced in the unorganized world are analogous to the more complicated results of vitality as seen in animal

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49. What is said of solid bodies? What is the effect of the preponderance of the attractive force? 50. What is said of the symmetry of solids? What of the bodies of animals? What of the organs of plants? 51. What laws govern the organic world? What is said of organic forms? How do the atoms arrange themselves in the inorganic world? What is said of these geometrical forms? What of the laws of crystallization?

and vegetable life. The regular forms which minerals and other solids take upon themselves are called CRYSTALS, and the laws which govern the aggregation of matter into such forms are called *the laws of crystallization.*

52. **Growth of organized and unorganized beings.**—In the mode of growth of crystals and of organized beings, we observe a striking difference. In the organic world, the individuals become more and more perfectly developed by the gradual absorption of different substances, and the assimilation of these within themselves, developing their organs, and after a time producing the perfect individual, whose powers soon decaying, death results, when a complete disorganization takes place. The crystal, on the other hand, is perfect at the first moment of its formation; its increase is from without, and owing to a force which is drawing like to like. This power of crystallization being a constantly acting force, the crystal does not necessarily undergo decomposition, and except from some change in circumstances, remains ever the same. Crystallization effects, then, in the unorganized, what the powers of vitality do in the organized world, and viewed in this its proper light, the science of crystallography rises from being only a branch of solid geometry, to occupy an exalted philosophical position.

The attraction which produces crystals, (attraction of aggregation,) reveals to us all that we know definitely of the ultimate and intimate constitution of matter. Since we cannot predicate anything of the whole which is not true of its parts, we may reason with logical exactness from the sensible properties of crystals, and the laws of crystallogeny, to the invisible and untangible forces which centre in the ultimate molecules of matter itself. In this view, the only just one, *crystallogeny*, (the theory of the formation of crystals,) and *crystallography*, (the description of crystalline forms,) become a most important and inseparable corner stone of Physics. Viewed usually only as a subordinate department of the comparatively obscure and humble science of mineralogy, or at most as only an adjunct of chemistry, it is not strange that crystallography should have been generally ignored

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52. What is said of the growth of organized beings? What of the crystal? What is said of the attraction which produces crystals? To what may we reason from the sensible properties of crystals? What is crystallogeny? How is crystallography generally viewed? What advantages do we derive from a knowledge of its laws?

by writers on natural philosophy. Not only is it true that, from a study of its laws do we derive our only exact notions of the ultimate constitution of matter, but the laws of heat, light, and magnetism are to be fully studied, only by the insight which we obtain of their more recondite phenomena, through the influence of crystalline substances upon those great physical forces.

The following pages are condensed, by permission, chiefly from Dana's mineralogy, 4th edition, to which the student is referred for fuller explanation of the system of notation used in the figures.

Definition of Terms used in Crystallography.

53. **Definition of terms.**—It is important to define exactly the meaning of the following terms in constant use in crystallography.

Planes or *Faces* are the surfaces which limit a crystal.

Edges are produced by the meeting of planes.

Plane angles are formed by the meeting of two lines or edges.

Solid angles are formed by the meeting of three or more planes.

The value (or measure) *of an angle* is the number of degrees, minutes, &c., of which it consists, and is determined by the arc of a circle which would be intercepted by the two lines forming the angle, the lines meeting in the centre of the circle.

A terminal plane, base or summit is the plane on which the figure rests and its opposite.

Lateral planes connect terminal planes, and a series of three or more planes, making with each other parallel intersections, is called a *zone.*

Terminal edges are the edges of the terminal planes.

Lateral edges are the edges produced by the meeting of the lateral planes.

Similar planes or faces are those whose corresponding edges are proportional and whose corresponding angles are equal. The similar planes of a crystal are not always equal to each other in size, one or two being often more extended than the rest. Such are called *distorted planes.*

Edges are similar that are formed by the meeting of faces

What connection has it with heat, light, &c. 53. What are planes, edges, and angles? How are angles measured? What are terminal and lateral planes and edges? What are similar planes? When are edges plane, and solid angles similar? What is an apex? What is meant by replacement, truncation and bevelment?

equally inclined to each other; they are liable to the same inequality as similar planes.

Plane angles are similar when equal, and contained within similar edges respectively.

Solid angles are similar when they are composed of an equal number of plane angles, of which the corresponding ones are similar.

Apex, (plural, *apices*,) the summit where three or more planes meet to form a solid angle about an axis.

Replacement.—An edge or angle is replaced when cut off by one or more secondary planes. Figs. 13, 15, *l l*, and *i i*.

Truncation.—An edge or angle is truncated when the replacing plane is equally inclined to the adjacent faces. Figs. 13, 15.

Bevelment.—An edge is beveled when replaced by two planes which are respectively inclined at equal angles to the adjacent faces. Fig. 25. Truncation and bevelment can only occur on edges formed by the meeting of equal planes.

A Triangle is a plane figure contained within three sides; the sum of its angles is 180°.

An Equilateral Triangle has its three sides equal and contains three equal angles.

An Isosceles Triangle has two equal sides which may contain either a right, an acute or obtuse angle; if the angle be less than a right angle it is called an acute triangle, if greater, an obtuse triangle.

The unequal side of an isosceles triangle is called the base.

A Scalene Triangle has three unequal sides and contains three unequal angles.

A Square is a plane figure contained within four equal sides, whose four angles are right angles.

A Rectangle is a four-sided plane figure, whose opposite sides only are equal. Its four angles are right angles.

A Rhomb is a four-sided figure whose sides are equal, having two acute and two obtuse angles.

A Rhomboid differs from the rhomb in having only its opposite sides equal.

Diagonals are lines crossing from one angle to another.

Axes are lines connecting points diagonally opposite, as the apices of opposite solid angles, the centres of opposite edges or faces. Figs. 1, 5, 10 and 23.

What is a triangle? Describe the different kinds of triangles? What is a square, rectangle, rhomb, and rhomboid?

Three axes are employed for the different systems in crystallography, (excepting the sixth,) whose length may be equal, or only two alike, or all unequal; they may also be at right angles to each other, or oblique.

Definition of Crystalline Forms.

A Prism is a column having any number of sides. In crystallography we have four and six-sided prisms, which may be either right prisms, (that is, erect,) or oblique prisms, (that is, inclined.)

Four-sided prisms occur of a number of kinds; their bases may be either square, rectangular, rhombic or rhomboidal. If the base is a square or a rectangle and the prism erect, *the eight solid angles are equal* and *rectangular;* the edges are twelve and may vary; for example,

A Cube is bounded by six equal sides, (the lateral sides being equal to the bases,) and the twelve edges are all equal, fig. 1.

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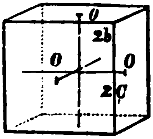

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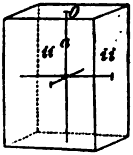

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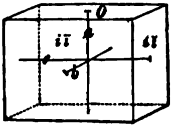

A Right Square Prism, fig. 2, has a square base and a height which may be either greater or less than its breadth; its sides are equal rectangles, the eight basal edges (four at each base) are equal to each other, but differ from the four lateral edges.

A Right Rectangular Prism, fig. 3, has a rectangular base and sides also rectangular, the opposites only equal; two edges at each base, differs from the other two, while the lateral edges are also different; hence there are three sets of edges, four in each set.

The base may also be a rhomb or rhomboid.

What are diagonals? What are axes? What is said of the axes employed in crystallography? What is a prism? What is said of four-sided prisms? What is a cube? A right square prism? A right rectangular prism? Draw these figures from memory.

A Right Rhombic Prism, fig. 4, has a varying height and a rhombic base. Its plane angles are two obtuse and two acute, with corresponding solid angles and lateral edges, the four lateral faces, like the basal edges, are equal.

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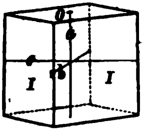

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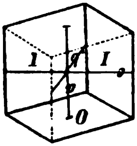

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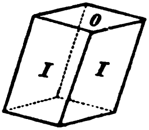

An Oblique Rhombic Prism, figs. 5, 6; (fig. 5, a front view, and fig. 6, a side view;) has a rhombic base and a varying height, the lateral faces are rhomboids. The lateral edges, like the basal edges, have two acute and two obtuse angles. When the height is equal to the breadth the form is

A Rhombohedron, fig. 23, composed of six equal rhombic faces.

A Right Rhomboidal Prism has a rhomboidal base and a varying height, only the two opposite sides and angles are equal, the lateral rectangular faces correspond to the basal edges; the opposites only are equal. This form is similar to fig. 4.

An Oblique Rhomboidal Prism, fig. 7, has a rhomboidal base and a varying height. The lateral faces are rhomboids. The edges of each base are of four kinds; for two opposite are longer than the other two, and of each pair, one is obtuse and the other acute. In this solid, therefore, only diagonally opposite edges are *similar*, and only opposite solid angles are equal.

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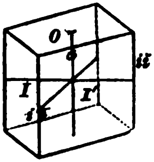

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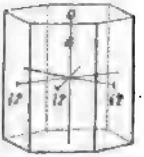

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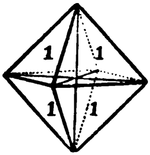

An Hexagonal Prism, figure 8, is an erect six-sided prism.

What is a right rhombic prism? An oblique rhombic prism? A rhombohedron? What is a right rhomboidal prism? Describe an oblique rhomboidal prism? What is an hexagonal prism?

An Octahedron has eight triangular faces; its form is like two four-sided pyramids united base to base. Three octahedrons are described.

The Regular Octahedron, fig. 9, has a square base and eight faces, equilateral triangles; its solid angles are six and equal, as also are its twelve edges. The plane angles are 60°, the interfacial angles are 109° 28′ 16″; this solid is symmetrical like the cube.

The Right Square Octahedron, fig. 10, has a square base, but a vertical height, greater or less than in the regular octahedron. Its faces are equal isosceles triangles. Its basal edges are equal and similar, but they differ in length from the eight equal pyramidal edges. The vertical solid angles differ from the basal.

The Right Rhombic Octahedron, fig. 11, has a rhombic base and a varying height; its faces are equal triangles; the basal edges are equal; the plane angles of the base and the pyramidal edges are of two kinds, two obtuse and two acute.

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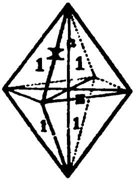

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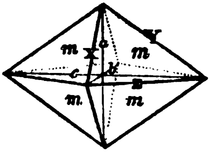

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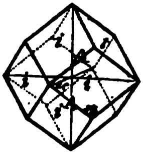

The Rhombic Dodecahedron, fig. 12, is bounded by twelve equal rhombs; it has twenty-four similar edges, fourteen solid angles; they are of two kinds. Eight obtuse, formed by the meeting of three obtuse plane angles, and six acute, formed by the meeting of four acute plane angles.

NOTE.—In studying this subject the pupil will find it of the greatest assistance to his easy comprehension of the forms mentioned, to produce them with a knife, from some soft substance like a turnip or a potato, which are more easily managed than chalk or wood, and neater than clay. Sets of crystalline forms and cards, with the outlines of the various forms prepared for cutting up, are furnished cheaply by the German chemical dealers for the use of schools.

What is an octahedron? Describe the regular octahedron. The right square and right rhombic octahedron. What is the rhombic dodecahedron?

Monometric System.

54. **The monometric system,** (from *monos*, one, and *metron*, measure,) includes the cube, fig. 11, the regular octahedron, fig. 9, and rhombic dodecahedron, fig. 12. Each of these forms is perfectly symmetrical, being equal in height, length and breadth. Their axes are three in number, of equal length, and at right angles to each other. In the cube, the axes connect the centres of opposite faces, (fig. 1,) in the octahedron the apices of opposite solid angles, (fig. 9,) and in the dodecahedron the apices of opposite acute solid angles, (fig. 12.) The relation of the axes in these solids to each other may be understood by deriving one form from the other. If in the cube (its faces are indicated by *o*) we truncate each of its eight solid angles, fig. 13 is first produced, and as the truncation proceeds, fig. 14, and finally a perfect octahedron. It will be noticed that the centres of *o*, the ends of the axes in the cube, correspond to the apices of the solid angles in the octahedron, which are also the ends of axes.

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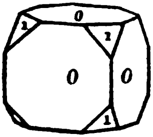

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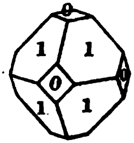

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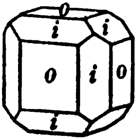

Again, if we replace each of the edges of the cube by planes, (*i*) equally inclined to the faces, as we continue the replacement, we obtain successively the forms represented by figs. 15 and 16; finally, as the planes *o*, disappear, we obtain the rhombic dodecahedron, fig. 13, the apices of its opposite acute solid angles, corresponding to the centres of the faces of the cube. If we truncate the

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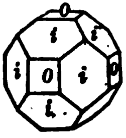

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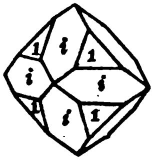

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54. What does the monometric system include? What of the symmetry of the forms in this system? What is said of their axes? What do they connect in the different forms? How may an octahedron be derived from a cube? How a rhombic dodecahedron?

edges of the octahedron, fig. 17, the planes (i) are reduced in size, and continuing the removal till these are obliterated, the rhombic dodecahedron results, and, as in the other cases, there is a perfect correspondence in position between its axes and the axes of the other forms. By a reversal of these processes we obtain from the octahedron and dodecahedron the cube, and the octahedron from the dodecahedron.

Dimetric System.

55. **The dimetric system,** (from *dis*, two-fold, and *metron* measure,) includes the square prism, fig. 2, and square octahedron, fig. 10, bearing the same relation to each other as the cube does to the regular octahedron. In this system there are three axes, all at right angles to each other, but only the two lateral are equal, the third or vertical axis being of varying length. In the prism, the axes connect the centres of opposite faces, (fig. 2,) in the octahedron the apices of opposite solid angles, (fig. 10.) If a square prism has each of its solid angles truncated, we shall have first, fig. 18, and finally the square octahedron is produced.

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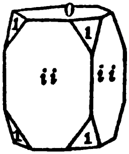

Trimetric System.

56. **The trimetric system,** (from *tris*, three-fold, and *metron*, measure,) includes the rectangular prism, fig. 3, the rhombic prism, fig. 4, and the rhombic octahedron, fig. 11. Each of these forms has its three axes at right angles to each other, and all are unequal in length. In a rectangular prism, (the base a rectangle,) the axes connect the centres of opposite faces, fig. 3. In the rhombic prism, (base a rhomb,) the vertical axis connects the centres of the bases, the two lateral axes connect the centres of opposite edges, fig. 4. In the rhombic octahedron (base a rhomb) the axes connect the apices of opposite solid angles, fig. 11. If the solid angles of the rectangular prism are removed, we have first, fig. 19, and finally the rhombic

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How may an octahedron be derived from a rhombic dodecahedron? 55. What does the dimetric system include? What is said of the axes in this system? What do they connect?

octahedron. The same result is obtained by removing the basal

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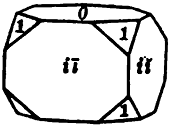

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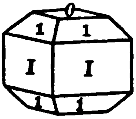

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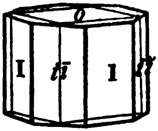

edges from a rhombic prism, as seen commenced in fig. 20. Again, replace the lateral edges of a right rectangular prism by planes equally inclined to both faces, and a right rhombic prism is the result; fig. 21 shows the relation of the two prisms to each other; the position of the axes in these forms may be seen to correspond.

Monoclinic System.

57. **The monoclinic system,** (from *monos*, one, and *klino*, to incline,) includes the right rhomboidal prism, (fig. 4.) and the oblique rhombic prism, (fig. 5.) In this system the three axes are unequal, the two lateral axes are at right angles with one another, the vertical is inclined to one of the lateral axes and at right angles with the other. In the right rhomboidal prism the axes connect the centres of opposite faces, (fig. 9.) In the oblique rhombic prism the vertical axis connects the centres of the bases, and the two lateral axes, the centres of opposite lateral edges, (fig. 5.) The truncation of the lateral edges of one prism finally produces the other. The relation of these prisms to each other is seen in fig. 22.

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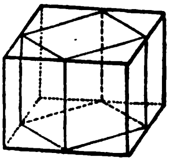

Triclinic System.

58. **The triclinic system,** (from *tris*, three, and *klino*, to in-

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How is a square octahedron derived from a square prism? 56. What does the trimetric system include? What do the axes connect in the different forms of this system? How is the rhombic octahedron derived from a rectangular prism? How from a rhombic prism? How is the right rhombic prism derived from a right rectangular prism? 57. What does the monoclinic system include?

cline,) includes the oblique rhomboidal prism, (fig. 7.) All the axes are unequal and oblique, the vertical axis connects the centres of the bases; the lateral axes connect the centres of the lateral edges, (fig. 7.)

Hexagonal System.

59. **The hexagonal system**, includes the hexagonal prism, (fig. 8,) and rhombohedron, fig. 23. In the hexagonal prism, fig. 8, the vertical axis connects the centres of the bases, the three lateral axes connect the centres of opposite lateral faces or edges and cross each other at an angle of 60°, at right angles to the vertical axis.

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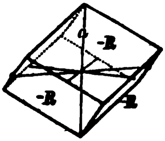

In the rhombohedron, two diagonally opposite solid angles consist of three equal obtuse or three equal acute plane angles; the diagonal connecting these solid angles is called the vertical axis; placed with this axis in a vertical position, the rhombohedron is said to be in position, and looking from above, it will be noticed that the lateral edges are at an equal distance from the vertical axis; the three lateral axes connect the centres of the lateral edges intersecting each other, as do the lateral axes of the hexagonal prism, at an angle of 60°. Placing the rhombohedron in position, if we remove the six lateral edges, replacing them by planes parallel to the vertical axis, there is produced a regular hexagonal prism, terminated by three-sided pryamids. If their vertical solid angles are also removed, the regular hexagonal prism results. If we remove from an hexagonal prism three alternate basal edges, and at the other extremity also, three edges, alternating with the first, as shown in fig. 24, and continuing the removal till the original form is obliterated, a rhombohedron is produced; it also results by removing, in a corresponding manner, the alternate solid angles from the hexagonal prism. When the plane angles forming the ver-

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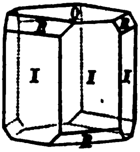

What is said of the length of the axes in the forms of this system? What do they connect? How is one prism derived from another? 58. What does the triclinic system include? What is said of the length of the axes in this system? What do they connect? 59. What does the hexagonal system include? What is said of the axes in the hexagonal prism? What of the axes in the rhombohedron? What is the appearance when the rhombohedron is placed in position?

tical solid angles are obtuse, the rhombohedron is called obtuse, and if acute, the solid is called an acute rhombohedron.

Modified Forms.

60. **Modified forms.**—If bodies in crystallizing assumed only the fundamental forms, there would be but comparatively little variety and beauty in crystalline solids; it is to the modification of the fundamental forms that we owe that endless variety of crystalline figures which we observe in nature and that are produced in the laboratory. These modified forms are called secondary or derivative forms, and are produced by the replacing of the edges and angles of the fundamental forms by planes, which are called secondary planes. The modifications of crystals take place according to two simple laws.

1st. All the similar parts of a crystal may be simultaneously and similarly modified. The forms thus resulting are called *holohedral* forms, (from *holos*, whole, and *edra*, face.)

2d. Half the similar parts of a crystal may be simultaneously and similarly modified; the forms thus resulting are called *hemihedral* forms, (from *hemisa*, half, and *edra*, face.)

A few of the secondary forms of the different systems of crystallization will be noticed.

Monometric System.

61. **Holohedral forms.**—By the bevelment of the edges of a cube we have first fig. 25, and finally fig. 26, called a *tetrahexahedron*, the faces *i* 2, being extended until *o* is removed.

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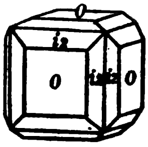

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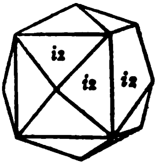

By replacing each of the solid angles of a cube by three faces

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How do we derive the hexagonal prism from the rhombohedron? 60. What is said of modified forms? What are holohedral forms? What are hemihedral forms? 61. How is a tetrahexahedron derived from a cube?

equally inclined, we have fig. 27, and finally fig. 28, called a *trapezohedron.*

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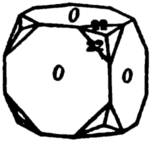

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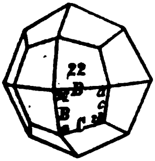

62. **Hemihedral forms.**—By truncating the alternate angles of a cube we have figs. 29 and 30, and finally the faces of the cube disappear, and there results for fig. 29, the tetrahedron, fig. 31, a three-sided pyramid; this form in seen in iron pyrites, and a similar form results, for fig. 30.

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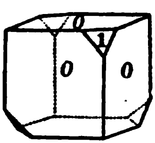

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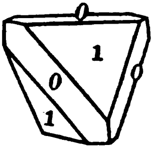

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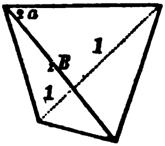

If the edges of a cube are replaced but by one of the two beveling planes, represented in fig. 25, we have figs. 32, 33, and finally, fig. 34, the pentagonal dodecahedron.

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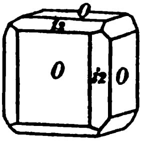

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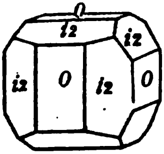

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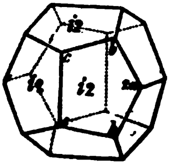

Dimetric System.

63. **Holohedral forms.**—The square prism has its lateral different from its basal edges; modifications of these two kinds of

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How is a trapezohedron derived from a cube? 62. What form results from truncating the alternate angles of a cube? How is a pentagonal dodecahedron derived from a cube?

edges take place independently of each other. The planes, including the lateral edges, are equal; these edges may therefore be beveled and truncated, which cannot be with the basal edgess, as they are contained within unequal planes.

If the lateral edges of a square prism are truncated, another square prism results, fig. 35; if beveled, eight-sided prisms, fig. 36,

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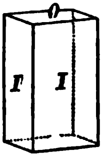

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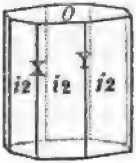

are produced, of different angles, according to the angles of bevelment. If the solid angles of a square prism be replaced by two

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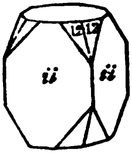

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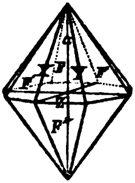

planes, as in fig. 37, a double eight-sided pyramid results, fig. 38.

64. **Hemihedral forms.**—If half the solid angles of a square prism be replaced by single planes, as shown in fig. 18, the scalene pyramid, fig. 39 results, while if two planes replace half the angles, fig. 40 is produced.

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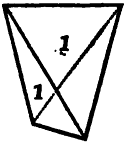

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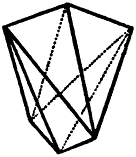

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63. What is said of the square prism? What forms result from the truncation and bevelment of the lateral edges of a square prism? How is a double eight-sided pyramid produced from a square prism? 64. How is a scalene pryamid produced from a square prism?

If on half of the angles only one of the two planes represented in fig. 37 is extended, and the plane on the opposite angle is on

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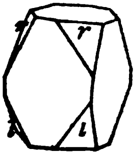

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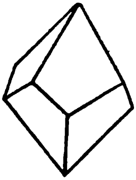


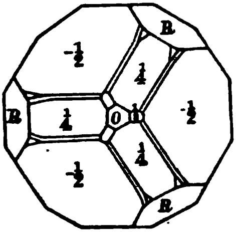
the same side of the edge, fig. 41, results; while if the plane is on the opposite side of the edge, fig. 42, is produced.

Trimetric System.

65. **Holohedral forms.**—It has been shown that a replacement of the lateral edges of a rectangular prism, produces a right rhombic prism; by varying the inclination of the replacing planes, different rhombic prisms are produced; a replacement of the basal edges produces other rhombic prisms, which are called (by Dana) *domes*, (from *domus*, house,) being placed like the roof of a house.

66. **Hemihedral forms.**—Two different kinds of hemihedrism occur in this system; the *monoclinic*, when the lower extremity of a crystal in front and its diagonally opposite differ in their modification from the upper extremity in front, as in tourmaline,

43



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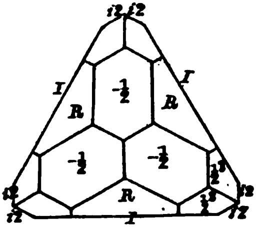
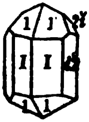


How the form, fig. 40? What of the other hemihedral forms? 65. How are different rhombic prisms produced from a rectangular prism? What are domes? 66. What different kinds of hemihedrism occur in the trimetric system?

figs. 43, 44; the *hemimorphic*, when all similar parts of one base are modified alike, but unlike the corresponding parts of the other as in topaz, figs. 45, 46.

45



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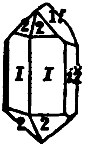
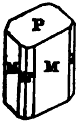


Monoclinic System.

67. **Monoclinic system.**—In the oblique rhombic prism, the lateral edges are two acute and two obtuse, therefore their secondary planes are unlike, fig. 47, the four lateral angles are similar, fig. 48, the basal edges are two obtuse and two acute, therefore, independently modified, fig. 49, shows the obtuse basal edges modified.

47



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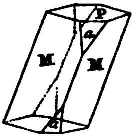

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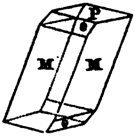
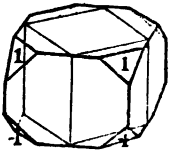


The oblique octahedron results from the replacement of the solid angles of the oblique rhombic prism; in this figure there are two sets of planes, in which 1, 1, are on the obtuse angles

50



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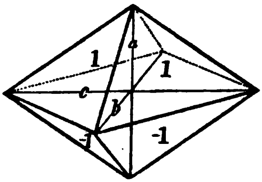


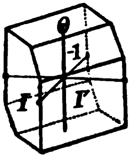
Give Examples. 67. What is said of the oblique rhombic prism? What of the oblique octahedron?

of the outer prism, while —1 —1 are on the acute angles; fig. 50 shows the commencement of the replacement, and fig. 51 shows the completed figure.

Triclinic System.

68. **Modifications.**—As only diagonally opposite edges or angles are similar, we can have in the crystals of this system but

52



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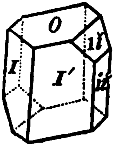

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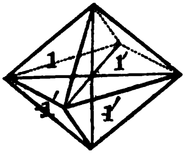
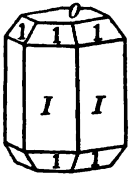


two planes alike, figs. 52, 53. By the replacement of the basal edges of the prism by homologous planes, an octahedron, having four sets of planes, may be produced, fig. 54.

Hexagonal System.

69. **Holohedral forms.**—In the hexagonal prism, the basal edges are alike, as also are the lateral edges and the solid angles. If each basal edge or basal angle is replaced by a single plane, as

55



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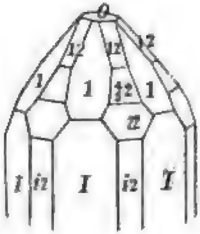

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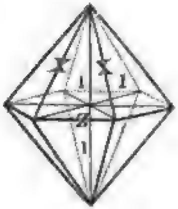

figs. 55, 56, there results a double six-sided pyramid, called a dihexagonal pyramid, fig. 57. When each solid angle is replaced by two similar planes, we have first fig. 58, and finally

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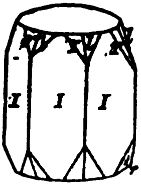
68. What is said of the modifications in the triclinic system? 69. How is the dihexagonal pyramid produced from the hexagonal prism? How the berrylloid? How is a scalenohedron produced from a rhombohedron?

a double twelve-sided pyramid, the berrylloid, results, fig. 59.

58



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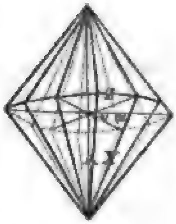

By replacing the lateral angles of a rhombohedron, there results a regular hexagonal prism terminated by a three-sided pyramid; while if the planes m, fig. 60, are enlarged till R is obliterated, an acute rhombohedron is produced. If, as in fig. 61, the lateral edges of a rhombohedron are beveled, a scalenohedron, represented by the dotted lines, fig. 61, results. This solid is included by twelve scalene faces. By the replacement of the lateral angles of a rhombohedron by two planes, other scalenohedrons result, as fig. 62.

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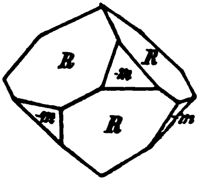

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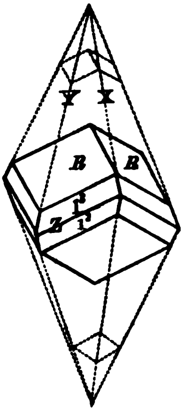

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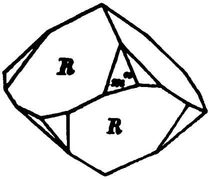

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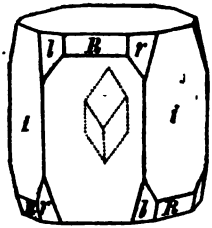
70. How does a rhombohedron result from an hexagonal prism? How a scalenohedron? How a six-sided pyramid? How is a trapezohedral double pryamid produced?

70. **Hemihedrism.**—There are a number of kinds of hemihedrism in this system. By the replacement of the alternate basal angles or edges of an hexagonal prism, a rhombohedron results, as has been shown. Fig. 58 is an hexagonal prism, with two planes on the angles, at either base; in hemihedral forms, half of these planes are suppressed. If the suppressed planes are first *r*, then *l*, fig. 63, alternate above and below, the form is a scalenohedron; if the occurring plane is the *r* on each angle of one base and the *l* on each angle of the opposite, as in fig. 64, a six-sided pyramid results. Again, the recurring planes may be the *r* of both bases, or the *l* of both bases, and there then results a trapezohedral double pyramid.

63



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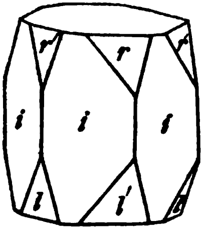
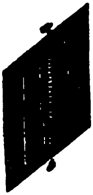


71. **Compound crystals.**—Sometimes we find two or more crystals united regularly and symmetrically together. The form, if composed of two individuals, is called a twin crystal. Fig. 65 is a simple crystal of gypsum; if it be bisected along *a b*, and the right half be inverted and applied to the other half, it will form fig. 66. If an octahedron, as fig. 67, be bisected

65



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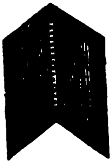

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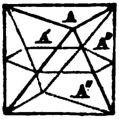

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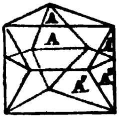

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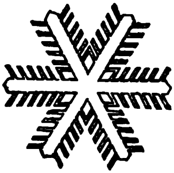
71. What is a compound crystal? What is said of the crystal of gypsum? How is the form, fig. 68, produced from an octahedron?

through the dotted line, and the upper half revolved half way

69



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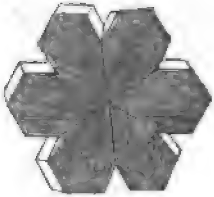

around be then united to the lower, it produces fig. 68. Both figs. 66 and 68 are twin crystals.

The imaginary axis, on which the revolution of half the crystal is made, is termed the axis of revolution, and the imaginary section, the plane of revolution. Compound crystals, composed of more than two individuals, are frequently observed, as in the case of the snow-flake, a not unusual form of which is represented by fig. 69, composed of six crystals meeting at a point, or of three crossing each other at right angles. Fig. 70 represents a compound crystal of chrysoberyl.

72. **Cleavage.**—By the application of mechanical force to crystals, we observe that they split in certain directions, leaving even and polished surfaces. The production of such surfaces, in causing the separation of the particles of the crystals, is called their *cleavage;* the planes along which the separation takes place are called *cleavage joints.* Cleavage is often obtained with great ease, as, for example, with mica, which may be separated by means of the fingers into thin leaves. Galena, again, cleaves easily, and as the three cleavage planes are at right angles to each other, a cube results. Calc spar also readily splits in three directions, and by this means a rhombohedron is obtained; while with fluor spar a cleavage of its solid angles produces an octahedron. The cleavage of many crystals is obtained with great difficulty, as, for example, with quartz and tourmaline; in others no cleavage can be produced, owing to the strong cohesion among the laminæ. In some crystals but one cleavage is visible, as with

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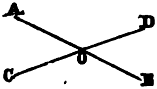
What is the axis of revolution in a compound crystal? What is said of snow flakes? 72. What is cleavage? What are cleavage joints? Give examples of easy cleavage. Examples of difficult cleavage.

mica; several have two; others three, as galena and calc spar; fluor spar has four, blende has six, while others have even more. We obtain by the cleavage of a crystal some one of the thirteen fundamental forms. Varieties of the same mineral have the same cleavage. Cleavage occurs parallel to the faces of the fundamental form, or along the diagonals; the facility of cleavage and lustre of the surfaces is always the same, parallel to similar faces.

73. **Goniometers.**—Instruments for determining the angles of crystals are called goniometers, (from *gonu*, angle, and *metron*, measure.) The principle of the common goniometer is, that when two straight lines cross each other, their opposite angles are equal, as when, fig. 71, the line *A E* crosses *C D*, the angle *A O D* is equal to the angle *C O E*, and *A O C* to *D O E*. Hauy's goniometer, fig. 72, consists of a light semi-circle of brass, accurately graduated into degrees, having a pair of arms which open and shut, moving on a central pivot, *O*, by means of the grooves *g h* and *n p;* these arms may be lengthened and shortened at pleasure, and the points *a c* are thus made capable of embracing the faces of any crystal whose angles we wish to determine.

71



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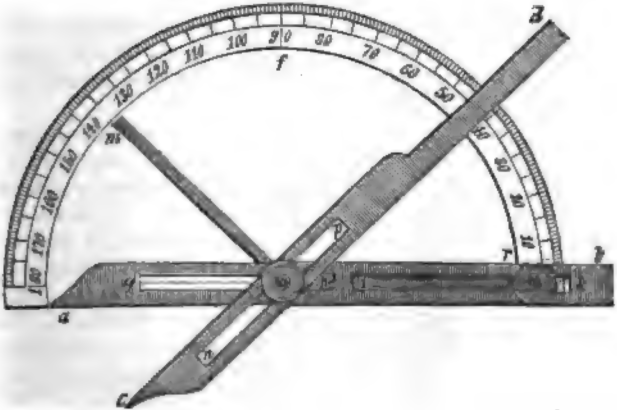


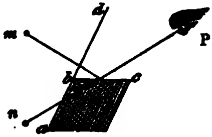
To measure an angle, we press the external arms of the com-

What do we obtain by the cleavage of a crystal? How does cleavage occur? 73. What are goniometers? What is the principle of their construction? What is Hauy's goniometer? How is a crystal measured by means of it?

pass against the faces of the crystal which enclose the angle, until they accurately touch those planes in directions perpendicular to the edge at which they meet; this done, we tighten the screw O, by which the arms are confined. As the opposite angles are equal, therefore the angle indicated on the arc, (45° in the present case,) is the angle of the crystal.

74. **Wollaston's reflecting goniometer.**—"The reflecting goniometer affords a more accurate method of measuring crystals that have lustre and may be used with those of minute size. The principle on which this instrument is constructed will be understood from the annexed figure, representing a crystal whose angle, *a b c*, is required. The eye looking at the face of the crystal *b c*, observes a reflected image of *m*, in the direction *P n*. On revolving the crystal till *a b* has the position of *b c*, the same image will be seen again in the same direction, *P n*. As the crystal is turned in this revolution till *a b d* has the present position of *b c*, the angle *d b c*, measures the number of degrees through which it is revolved. But *d b c* subtracted from 180° equals the required angle of the crystal. The crystal is therefore passed in its revolution through a number of degrees, which subtracted from 180°, gives the required angle. This angle evidently might be obtained by attaching the crystal to a graduated circle which should turn with the crystal."

73



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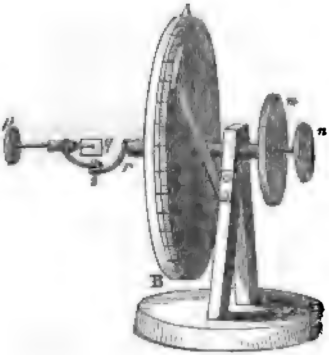

"This object is conveniently accomplished by the ingenious and simple contrivance of Wollaston, fig. 74. *A B* is the circle graduated to half degrees. By means of the vernier, *V*, minutes are measured. The wheel *m*, is attached to the main axis and moves the graduated circle, together with the adjusted crystal. The wheel is connected with an axis that passes through the main axis, which is hollow for the pur-

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74. What are the advantages of Wollaston's reflecting goniometer?

pose, and moves merely the parts to which the crystal is attached, in order to aid in its adjustment. The contrivances for the adjustment are at *p*, *q*, *r*. To use this instrument, it must be placed on a small stand or table, and so elevated as to allow the observer to rest his elbows on the table. The whole, thus firmly arranged, is to be placed in front of a window, distant from the same from six to twelve feet, with the axis of the instrument parallel to it. Before operation, a dark line should be drawn below the window, near the floor, parallel to the bars of the window; or, what is still better, on a slate or board placed before the observer, on the table."

"The crystal is attached to the movable plate *q*, by a piece of wax, and so arranged that the edge of intersection of the two planes, including the required angle, shall be in a line with the axis of the instrument. This is done by varying its situation on the plate *q*, or the situation of the plate itself, or by means of the adjacent joints and wheel *r*, *s*, *p*."

"When apparently adjusted, the eye should be brought close to the crystal, nearly in contact with it; and on looking into a face, part of the window will be seen reflected, one bar of which must be selected, or a cord stretched across the window for the experiment. If the crystal is correctly adjusted, the bar or cord will appear horizontal, and on turning the wheel *n*, till this bar, reflected, is observed to approach the dark line below, seen in a direct view, it will be found to be parallel to this dark line and ultimately to coincide with it. If there is not a perfect coincidence, the adjustment must be altered until this coincidence is obtained. Continue then the revolution of the wheel *n*, until the bar or cord is seen by reflection in the next face, and if here there is also a coincidence of the reflected bar or cord with the dark line seen direct, the adjustment is complete; if not, alterations must be made and the first face again tried. A few successive trials of the two faces will enable the observer to obtain a perfect adjustment."

"After adjustment, 180° on the arc should be brought opposite *o*, on the vernier. The coincidence of the bar and dark line is then to be obtained by turning the wheel *n*. As soon as obtained, the wheel *m* should be turned until the same coincidence is observed, by means of the next face of the crystal."

What is the principle of its construction? What is the contrivance of Wollaston? How is the crystal attached and adjusted? How is the determination made?

"If a line on the graduated circle now corresponds with *o* on the vernier, the angle is immediately determined by the number of degrees marked by this line. If no line corresponds with *o*, we must observe which line on the vernier coincides with a line on the circle. If it is the 18th on the vernier, and the line on the circle next below *o* on the vernier, marks 125°, the required angle is 125° 18′, if this line marks 125° 80′, the required angle is 145° 48′."

"Some goniometers are furnished with a small polished reflector attached to the foot of the instrument, below the part *s*, *q*, and placed at an oblique angle so as to reflect a bar of the window. This is an important improvement, as the reflected bar answers the purpose of a line drawn below the window, and is more conveniently used. This reflector may be easily added to the common instruments, placing it at an angle of about 45°, or such as will reflect the bar to the eye, when looking toward the crystal, while observing."

75. **Constancy of crystalline form.**—Each crystalline solid has a definite form of its own, and as we distinguish the individuals of the animal and vegetable worlds by their external appearance, so by the difference in form may the substances which constitute crystalline masses likewise be identified and distinguished.

For example: common salt crystallizes in cubes, alum in octahedra, epsom salts in four-sided prisms, saltpetre in six-sided prims, &c.

The crystals of many substances are so distinct from each other that their difference would at once be noticed by the most casual observer; but if other substances are selected whose crystalline forms are apparently the same, careful observation will show that each has some peculiarity which distinguished it from the others. This difference would be seen, if not in the number of the faces, in the value of their included angles, or in the facility and direction of their cleavages. Many species might at once be identified by the measurement of even one of their angles. It is upon this individuality of form of different species, that the value of crystallography to the chemist and mineralogist depends.

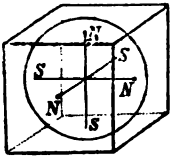
What is the advantage of the polished reflectors attached to some goniometers? 75. What is said of the constancy of crystalline forms? Give examples. How are crystals distinguished whose forms are apparently the same?

76. **Shape of the crystalline molecules.**—The form of the ultimate crystalline molecules is supposed to be *spherical* for the cube and other monometric forms, *spheroidal* for the square prism, &c., and *ellipsoidal* for forms of the last four systems. The ellipsoid is either that of revolution, that is, a form produced by the revolution of an ellipse upon one of its axes, (called the ellipsoid of revolution,) or it is a flattened ellipsoid.

77. **Direction of the crystalline forces.**—As the same body solidifying under the same circumstances assumes always the same form, it is evident that the atoms of which it is composed are attracted to each other by certain forces in definite directions. If these forces acted only in one direction there would be formed but a line of spheres; if in two directions, a figure of two dimensions, a plane would be produced; while if in three directions, there would be formed a solid of three dimensions, bounded by six faces, as the cube. It follows that in each crystalline molecule the action of the forces is in three directions, which directions are called *axes* and their terminations *poles*. These poles are the centres of forces; the strength of attraction, &c., as in the case of all forces, acting in right lines, varies inversely as the square of the distance.

78. **Equality of the axes in crystalline molecules.**—The equality of the axes in crystalline molecules varies greatly. These molecules being either spheres or ellipsoids, the three axes are either the fundamental ones or the diameters of the particles. In a sphere, fig. 75, the axes are of equal length and at right angles to each other; hence the molecules will combine, and a cube will be formed by means of the molecules, as by the aggregation

75



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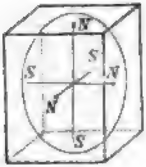

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76. What is the shape of the crystalline molecules? 77. What is said of the direction of the crystalline forces? Why do we suppose that these forces act in three directions? 78. What is said of the equality of the axes in crystalline molecules? What of the axes in a sphere?

of an equal number of cubes. In the ellipsoid the three axes may be all unequal, or two of them alike. The ellipsoid of the rectangular prism, fig. 76, has its axes at right angles to each other, but all of them unequal; the right rhombic prism has a molecule similar to the rectangular prism, but its lateral axes, which connect the centres of opposite faces, are obliquely inclined toward one another. The number of forms which can be produced by variations in length and the obliquity of the axes is exceedingly great.

79. **Conditions of crystallization.**—As crystallization tends to force the molecules of a substance to arrange themselves in a definite manner, it is necessary, if we wish to crystallize a body, that its molecules be in such a condition that they are at liberty to obey uncontrolled the crystalline forces which are acting upon them. The liquid and gaseous conditions of matter allow the greatest mobility among their particles, and one of these forms all bodies must assume before they are enabled to crystallize perfectly.

80. **Crystallization by liquefaction.**—Solid bodies may be liquefied by two means. *a. By elevation of temperature*, in consequence of which the body melts; this is the case with metals generally, sulphur and many salts.

By simply cooling the melted portion of bismuth or sulphur, a crystalline mass will be formed, but more perfect crystals may be produced by allowing the liquid to cool until a crust is formed over the surface. If this is then pierced, and the still liquid portion within turned out, the interior of the vessel will be found, after cooling, filled with crystals; in the case of sulphur, with long slender prisms, (oblique rhombic prisms,) if bismuth, with obtuse rhombic prisms.

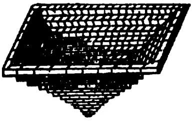
b. By solution.—Many solids dissolve in water or other liquids, forming a solution in which all crystalline attractions are subordinate, or disappear entirely. Most salts, as common salt, saltpetre, &c., will dissolve in water, others are soluble in alcohol. Many substances are much more soluble in hot than in cold water, and by slow cooling, the excess is deposited in very perfect crystals.

What is said of the axes in the different ellipsoids? 79. What are the necessary and best conditions for the crystallization of a body? 80. What are the methods of crystallization by liquefaction? Give a description of the first; of the second. Mention examples of each.

This is true of alum and Glauber's salt, and a multitude of other compounds, and also of the elements, sulphur and phosphorus, when dissolved by the aid of heat in bisulphuret of carbon.

Some substances are equally soluble in cold as in hot water, and crystals are obtained from their solutions only by evaporation with or without the aid of heat.

77



Common salt is an example of such a substance; when evaporated very gently, as by solar heat, perfect cubes are formed; if rapidly, as by fire, a confused mass of irregular crystalline grains result. Sometimes the floating crystals, as they grow in weight continually, but slowly, sink, giving rise to the curious hopper-shaped crystals seen in fig. 77.

Other substances in solution may be obtained in a crystalline state by precipitation; that is, by the addition to the liquid of some other dissolved body, which causes the first to become insoluble, and precipitates as a crystalline powder. Analytical chemistry presents us numerous examples of this mode of crystallization, due to the formation of new compounds of a less solubility than either of the substances employed.

81. **Crystallization from the gaseous state, or sublimation.**—Many substances, by an elevation of temperature, assume the vaporous or gaseous condition, and upon the cooling of these vapors, the substances are deposited in crystals.

This is the case with camphor, which vaporizes and condenses at common temperature in the jar of the apothecary, in distinct and brilliant crystals upon the cooler surface. Iodine, when heated, becomes a violet vapor, and this, on cooling, condenses on the cooler portion of the containing vessel, in black crystals of the rhombic system; other instances of crystallization from the gaseous state are arsenic, sulphur and sal ammoniac.

82. **Rapidity of crystallization.**—The more slowly a liquefied or vaporized body is brought into the solid state, the fewer but more perfect are the crystals. If the crystallization proceeds rap-

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How is the crystallization of a substance effected which is equally soluble in a hot or a cold liquid? Mention an example. What is said of crystallization by precipitation? Give examples. 81. What is sublimation? Give examples of sublimation. 82. What is said of the rapidity of crystallization?

idly, there result many crystals but imperfectly developed. To obtain large and perfect crystals, a solution, as of alum, not quite saturated, is slowly cooled; a few distinct crystals are thus formed; the more perfect are placed separately from one another in a slightly warm solution of alum, which has a little more of the substance dissolved than it can hold up at the ordinary temperature; upon cooling, this excess is deposited upon the small crystals which are placed in the solution. By turning the crystals frequently and replacing the solutions as they become cold and exhausted, crystals of large size and perfect regularity are obtained. This has been termed the *nourishing* of crystals.

83. **Production of crystalline structure by vibration.**—The tough and fibrous character of iron is produced by art, and the metal of this description has a tendency to assume its more natural condition of crystallized iron. Continued vibration produces this effect after a certain time.

Masses of iron exposed to constant vibration, as the axles of rail cars, the shafts of machinery, &c., fibrous and tough at first, gradually alter their molecular condition, and become crystalline and brittle. The broken axle of a rail car often reveals a very distinct crystalline structure. It may be mentioned, that in the same bar all parts are not to the same degree affected; those parts which are most exposed to vibration, are found to undergo a more dedided change.

84. **Development of crystalline structure.**—1. *Corrosive fluids*, (as acids,) will often develop a crystalline structure in a mass, (as of iron,) in whose polished surface the eye detects no appearance of such structure. The outlines of the crystals in the mass are less soluble than other portions, and thus remain in relief while the softer parts are corroded and removed.

Thus when tin plate is washed with a dilute acid, crystalline forms are seen to cover it, resembling frost-work on a window pane; tin plate, thus treated and afterwards varnished, forms the *moirée metallique*. By treating polished plates of meteoric iron in the same way, long lines intersecting each other to form triangular figures,

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Give an example of the nourishing of crystals. 83. What effect has vibration on the molecular condition of a solid? Give examples. 84. How may a crystalline structure often be developed? What is said of tin plate? Of meteoric iron?

more or less fine on different specimens, are seen to cover it; these forms are called Widmannstattain figures.

2. *By time.* Although a body cannot form large and perfect crystals, unless it become either liquid or gaseous, yet we find many cases of amorphous bodies in time becoming crystalline, without leaving the solid state.

Sugar candy, transparent and amorphous at first, becomes gradually opaque and crystalline. Again, arsenious acid, heated quickly or under pressure, melts to a transparent colorless glass; this, after a few months, becomes white, opaque, and crystalline. Glass, by long continued heat, becomes, even while solid, quite opaque and crystalline. (Reaumer's porcelain.) Again, brass and silver, when first cast, possess considerable toughness, and their fracture furnishes no evidence of crystalline arrangement; by repeated heatings and coolings, and especially by vibration under tension, a different arrangement of the molecules results, the mass becomes brittle and sometimes disintegrates, the surface of the fracture showing a distinct crystalline structure; this is very often observed in common brass wire.

85. **Separation of salts by crystallization.**—As salts possess different degrees of solubility, crystallization is often resorted to to separate them from one another. At a certain degree of concentration of a liquid, containing a number of salts in solution, one of them will be deposited, the rest remaining dissolved. If the salts have the same crystalline form, they cannot be separated from each other in this way. By repeated crystallizations of impure salts, we may often obtain them perfectly pure; the evaporation being carried on gently, the molecules are deposited slowly, thus diminishing the entanglement of the impurities among the crystalline particles. The crystals thus produced, freed as much as possible from the liquid portion, (the mother liquid,) are again dissolved and re-crystallized, and by repetitions of this process the pure salt is obtained.

86. **Sudden crystallization.**—There are certain remarkable facts connected with the crystallization of bodies, a few of which will be noticed.

What is said of amorphous bodies becoming crystallized by time? Mention the examples of sugar candy and arsenious acid. What effect have repeated heatings and coolings upon brass, &c.? 85. How are many salts separated by crystallization? How are salts obtained perfectly pure? 86. What is said of sudden crystallization?

Some solutions may be cooled below the temperature at which they ordinarily crystallize and still remain liquid, provided that they are kept perfectly at rest and in closed or covered vessels; but the addition of a solid, or the agitation of the liquid, causes them immediately to crystallize.

A solution of Glauber's salts, (sulphate of soda,) in its own weight of hot water, slowly cooled in a closed flask, (best closed when the solution is boiling,) will remain fluid indefinitely, provided the vessel is kept at rest. When, however, the cork is withdrawn, the concussion of the air, a slight jar, or a single crystal of the salt let fall into the fluid, will instantaneously convert it into a solid mass of confused crystals.

Again, water may be cooled to 26° or 27° F., which is 6 or 7° below its ordinary freezing point, without solidifying; but, if it is shaken or touched with anything solid, crystals of ice dart through it, and soon the greater part becomes a solid mass, the temperature of which rises to 32° F.

Every winter, in this latitude, gives us abundant demonstrations of this fact in our own experience.

87. **Change of dimensions.**—Expansion at the moment of solidification is a fact of familiar occurrence, and is owing to a new arrangement of the crystallogenic molecules in the act of crystallizing.

Thus water, whose particles are spherical, expands about one-ninth of its volume on becoming ice, (which has a rhombohedral form,) and, as is well known, exerts such force in undergoing this physical change as to burst the strongest vessels of wood or metal, and even to rend solid blocks of granite.

Type metal, an alloy of lead and antimony, has the same peculiarity, and hence sharp and perfect casts are made by it, as well as by bismuth. On the other hand, lead, copper, gold, and silver, crystallize in forms of the monometric system, and therefore occupy less space after than before solidification; hence they shrink in the moulds and are unfit to produce sharp casts.

88. **Development of heat.**—A development of heat takes place in the crystallization of all bodies. When the crystallization is slow, the amount of heat developed at once during crystalliza-

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Give the example of Glauber's salts, and of water. 87. What is said of expansion during crystallization? Give the examples of water and type metal. What is said of lead, copper, &c.

tion is very inconsiderable, and in most cases the rise of temperature cannot be observed; when, however, the crystallization is rapid, the effect is decided, and in many instances, the amount of heat developed is truly surprising.

Hashoff mentions a remarkable rise of temperature in the crystallization of acetate of soda, a highly concentrated solution of which cooled to 50° F., remained liquid; upon stirring with a glass rod, it solidified into a fibrous mass, and the temperature rose to 138° F.

89. **Development of light.**—Crystallization, in rare cases, is attended with the development of a brilliant sparkling light.

A hot solution of arsenious acid, in hydrochloric acid, left to cool, deposits crystals, and as each separates, a vivid flash accompanies it. A solution of sulphate of potash is often seen to develop light while crystallizing. So also, the mixed solutions of the sulphates of potash and soda; sulphate of potash and common salt, and other similar cases, after these compounds have undergone fusion, present, upon crystallizing, a similar appearance.

The conditions necessary to produce this phenomenon are but very imperfectly understood, and it does not always happen even under apparently the same circumstances which have before produced it. This development of light is supposed to depend in every case on the passage of the body from the amorphous to the crystalline state. When crystals are suddenly broken, light, (possibly electrical,) is also evolved.

Thus, where two lumps of crystalline white sugar are rubbed together in a dark place, a distinct flash is seen; also when the laminæ of mica are torn suddenly apart.

90. **Amorphism.**—Amorphism is that state of a solid in which there is no trace of a crystalline structure; examples of such a state are seen in common glass, gun-flint, wax, obsidian, sugar candy, &c. An amorphous body, having no planes of cleavage, is broken in one direction as easily as in another. Bodies are

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88. What is said of the development of heat during crystallization? Give an example. 89. Mention examples of the development of light during crystallization. Are the conditions for this phenomena well understood? Upon what is it supposed to depend? 90. What is amorphism?

generally more soluble, less hard and dense, in the amorphous than in the crystalline state.

The property of toughness, seen, as for example, in emery, (amorphous corundum,) and horn stone, (amorphous quartz,) is much more highly developed in the amorphous substance, than in the crystalline variety.

An amorphous body may be produced in a number of ways; for example, by fusion, as in the case of glass; by evaporation of solutions, as those of the gums and glue in water; and by precipitation from their solutions, as is the case with alumina and phosphate of lime.

91. **Dimorphism.**—A substance which crystallizes in two systems, or takes two forms in the same system, which are incompatible with each other, that is, whose corresponding angles render it impossible to reduce them to the same form, is said to be dimorphous, (from *dis*, twice, and *morphe*, form.)

Sulphur is an example of a dimorphous body; we have spoken of its crystallization before; from its solution in sulphuret of carbon, it crystallizes in rhombic octahedrons; the crystals resulting from fusion are oblique rhombic prisms; these forms belong to different systems. Carbonate of lime, (in aragonite,) crystallizes as right rhombic prisms, and (in calc spar) as obtuse rhomboids. Oxyd of titanium occurs in two forms belonging to the same system, but these forms are incompatible. Carbon is dimorphous, crystallizing as diamond and graphite in forms belonging to different systems; so also is sulphuret of iron. Among the elements which are dimorphous, may be mentioned, besides sulphur and carbon, also antimony, arsenic, phosphorus, and copper.

In certain cases of dimorphous bodies, one form of the crystals, on being subjected to the temperature at which the other form is assumed, are found to lose their transparency, and although their external form may be preserved, yet the mass is made up of small crystals having the second form.

92. **Temperature.**—Temperature is supposed to be one of the chief causes which determine, in a dimorphous body, the form its crystals shall take.

What is said of amorphous bodies? What of emery and horn stone? 91. What is dimorphism? Give examples of dimorphous bodies.

Thus iodid of mercury sublimes at a gentle heat as square based octahedra belonging to the dimetric system; at a higher temperature the sublimate forms crystals belonging to the monoclinic system. Another instance is seen in carbonate of lime, a solution of which in water containing carbonic acid, allowed to evaporate spontaneously, deposits microscopic crystals of calc spar; it is observed of the same solution, that evaporated at 212°, the greater part of the salt is crystallized as aragonite; at a higher temperature, when fused under pressure, we obtain the carbonate of lime in the same form (calc spar) as when its solution is allowed to evaporate slowly.

93. **Difference in physical properties.**—We observe a remarkable difference in the physical properties of dimorphous bodies, accompanying their change of form as regards specific gravity, color, &c.

1. *Specific gravity.*—Sulphur and carbonate of lime offer good illustrations of the different specific gravity of the same substance, crystallized in two forms. Octahedral crystals of sulphur has the specific gravity of 2·05, while the prismatic crystals obtained from fusion have a specific gravity of 1·98. We can form crystals of aragonite by precipitation, having the specific gravity of 2·949; if these are allowed to remain in the liquid in which they were precipitated, they are gradually converted into calc spar, and have the specific gravity of 2·719.

2. *Color.*—The two forms of iodid of mercury have different colors. The square octahedra being yellow, while the second form, produced at a higher temperature, is a scarlet red. Again, with bisulphuret of iron, one form is of a bronze yellow color, (marcasite,) while the other, (white iron pyrites,) has a color approaching tin white.

3. *Difference in chemical properties*, also accompanies difference in form of dimorphous bodies. A striking example of this is seen in the case of sulphuret of iron, marcasite being remarkably permanent, water and air having no effect upon it; while the white iron pyrites, when exposed to most air, absorbs oxygen with avidity, and finally is converted into protosulphate of iron, (green vitriol.)

4. *Stability of form.*—The two forms of a dimorphous body

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92. What is said of temperature affecting dimorphous bodies? Mention the examples of iodid of mercury and carbonate of lime. 93. What is said of the specific gravity of dimorphous bodies? What of their color? What is said of the difference in chemical properties?

are not equally stable; one form appears as the more natural, and the other is seemingly forced upon it, so that time, or a slight change of circumstances, will cause an alteration in its molecular arrangement, causing it to assume the other form. The prismatic crystals of sulphur, gradually lose their transparency, and are soon converted into a mass of right rhombic prisms, identical with those obtained from the solution of sulphur in sulphuret of carbon. The rhombic prisms of arsenious acid, when exposed to the air, fall into a dull white mass, which is an assemblage of octahedrons. A crystal of aragonite, exposed to a low red heat, forms a coarse powder, which consists of crystals of calc spar. If the yellow modification of iodid of mercury is crushed, the point subject to friction immediately becomes scarlet, and gradually this color extends over the whole mass; a sensible mechanical movement may be observed, pending this change, all of the crystals changing to the form usual to the scarlet variety.

94. **Trimorphism.**—(From *tris*, three times, and *morphe*, form.) A substance which crystallizes in three forms, belonging to different systems of crystallization, or to the same system, but incompatible with each other, is trimorphous.

Sulphate of nickel exhibits this peculiarity; below 59°F it crystallizes in right rhombic prisms, between 59° and 68°, in acute square based octahedrons; above 86°, in oblique rhombic prisms. These three forms belong to different systems. Sulphate of zinc, seleniate of zinc and seleniate of nickel, also crystallize in the same forms as does sulphate of nickel.

95. **Polymorphism.**—As it is not improbable that substances may be found to crystallize in more than three forms, the word polymorphism, (from *polus*, many, and *morphe*, form,) has been proposed to include all cases, no matter what may be the number of forms which a body assumes.

96. **Pseudomorphism.**—(From *pseudos*, false, and *morphe*, form.) A pseudomorphous crystal is one that has a form foreign to the species to which it belongs. This change of form is accomplished in a number of ways.

1. *By alteration.*—In which some of the constituents of the mineral are removed or exchanged, and others added.

What of the stability of form of dimorphous bodies? Mention the example of sulphur, iodid of mercury, &c. 94. What is trimorphism? Mention examples of trimorphous substances. 95. What is meant by polymorphism? 96. What is a pseudomorphous crystal?

As, for example, with anhydrite, gradually changing to gypsum by the absorption of water; or iron pyrites, which by the loss of sulphur and the absorption of oxygen and water, becomes red or brown iron ore; again, galena (sulphuret of lead) is converted into sulphate of lead by the absorption of oxygen alone.

2. *By replacement.*—As petrified wood has been changed into stone by the gradual decay of its mass, and a corresponding replacement by the petrifying substance, in a similar manner certain crystals, on undergoing solution, have had, with equal progress, their cavities filled. Crystals thus formed are called pseudomorphs by replacement.

Examples of this class are quite numerous; among them are the replacement of calc spar by gypsum, heavy spar by calc spar, &c.

3. *By infiltration.*—Pseudomorphs by infiltration are formed when crystals are gradually removed by solution, and leaving cavities exactly corresponding to their form, by infiltration have had these cavities completely filled with another species, whose figure will then resemble the first.

Thus cubic crystal of salt in clay might gradually be removed, and its place supplied by gypsum.

4. *By incrustation.*—This class of pseudomorphs is formed by the incrustation of one mineral by the mass of another, the latter being deposited upon the first in such a state that it is completely inclosed; the mass within is afterwards dissolved away, leaving a cavity behind, which perfectly corresponds to the original crystal.

Crystals of fluor spar having been subjected to such a treatment, have left hollow crystals of quartz.

97. **Causes of pseudomorphism.**—The causes which produce pseudomorphs are, water, which exercises a more powerful action than might be supposed. When the water is cold, it contains carbonic acid in solution, and then decomposes many mine-

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Mention examples produced by alteration and change in chemical composition. How is a pseudomorph, by replacement, produced? Mention examples. How are pseudomorphs by infiltration formed? Mention a possible example. How are pseudomorphs by incrustation produced? Mention an example.

rals, even those which are apparently unalterable, such as hornblende, feldspar, &c.; when hot, its action is more decided, and combined with pressure, its solvent powers are so great that even silicic acid, (sand,) one of the most insoluble of substances, is dissolved largely by it. The known chemical reactions which would occur in waters holding in solution different compounds, would account for many of these changes; the action of the exhaling gases from the earth, whether or not in conjunction with volcanic action, must exert a decided influence; while the gradual oxidation of many minerals, and the reactions which might occur with their products, show that the atmosphere exercises a powerful effect in the production of this class of phenomena.

98. **Isomorphism.**—Isomorphism, (from *isos*, similar, and *morphe*, form,) signifies identity of crystalline form. Its application in chemistry is limited to those substances which not only possess the same form, but also an analogous chemical composition. Thus it is not usual to speak of octahedral alum and diamond as being isomorphous substances, although their crystalline form is the same; but the term is applied to those bodies which, like magnetic oxyd of iron, ($FeO.Fe_2O_3$) chrome iron ore, ($CrO.Cr_2O_3$) and spinel, ($MgO.Al_2O_3$,) have not only the same form, but also an analogous chemical composition, and are therefore truly isomorphous.

It is found that compounds whose chemical composition is the same, although they may have a close similarity in form, yet careful measurements show a difference in the length or inclination of their axes.

Such a difference is observed in the case of the carbonates of zinc, magnesia, iron and lime, all of which crystallize in rhombohedra, yet their corresponding angles are not identical, but show a difference, amounting in one case to 3° or 4°.

These differences may arise (Kopp) from a difference in the atomic volume of their ultimate molecules. We must remember, also, that iron and zinc crystallize in different systems, and it is not remarkable, therefore, that their corresponding compounds should show a slight difference in form.

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97. What is said of the action of water in producing pseudomorphs? What of waters holding in solution different compounds? What of the atmosphere? 98. What is meant by isomorphism? Give examples of isomorphous substances. How are slight differences in the forms of isomorphous compounds accounted for?

Isomorphous bodies replace each other in chemical compounds without producing any alteration in the crystalline figure of that compound, excepting sometimes small angular differences. With certain simple substances, possessing the same crystalline form, the corresponding compounds of these elements with other bodies, have also the same crystalline figure.

Arsenic and antimony, for instance, crystallize as acute rhombohedrons. Arsenious acid, (AsO_3,) has the same form as antimoniouss acid, (SbO_3); further, it is found that many of the salts of arseniou acid have the same form as the corresponding salts of antimonious acid; certain other elements, whose crystalline form in the separate state is unknown, are found to be isomorphous in certain of their compounds. Thus the oxyds of the metals manganese, magnesium, zinc and iron, are isomorphous in their combinations with carbonic, sulphuric and selenic acids.

It sometimes happens that a single atom of one element in a compound will be replaced by two or more atoms of another element without its crystalline form being altered, as is the case with chlorid of ammonium, (NH_4 Cl,) and chlorid of potassium, (KCl,) the one equivalent of nitrogen and four of hydrogen being replaced by one of potassium. Two equivalents of sulphur are isomorphous with one of antimony and one of arsenic.

It has also been observed that one atom of magnesia, protoxyd of iron, or of manganese, may be replaced by three atoms of water, or one atom of copper, by two atoms of water without change in its crystalline form. One of the most interesting instances of replacement occurs in the case of common alum, composed of potash, alumina, sulphuric acid and water, (having the formula $Al_2O_3.3SO_3+KO.SO_3+24HO$,) we may replace the potash by soda, or ammonia, and the alumina by sesquioxyd of iron, or sesquioxyd of chromium, without its crystalline form being altered. This replacing in a compound of one of its elements by another, isomorphous with it, occurs in the proportions, by weight, indicated by the chemical equivalents. Thus in the case of the alum just referred to,

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What is said of isomorphous bodies replacing each other? What is said of the corresponding compounds of arsenic, antimony, &c.? What is said of the replacement of one atom of one element by two or more of another? Give examples of such replacements. Mention the replacement occurring in the case of common alum. In what proportions, by weight, do the replacements occur?

the potash is not replaced by an equal weight of soda, but the transfer is made in the proportions indicated by their equivalents being 47· potash replaced by 31· soda, and in a similar manner for the other elements.

Strength of Materials.

99. **By strength of materials** is understood the resistance of solid bodies to forces which tend to separate their particles by *tearing*, *breaking*, or *compressing* them. Experiments to determine the laws of this resistance are obstructed by practical difficulties, arising from the great forces which must be applied, and from the inequalities of strength in the materials themselves. As the variations are more numerous, experiments must be multiplied, so that the extremes of strength and weakness may balance each other in the law finally deduced. The details of this subject belong to architecture and engineering, in which arts it is of the highest practical importance, but some of the general results of experiment will not be inappropriate in an elementary work on Physics.

100. **The absolute strength, or tenacity of a body**, is the resistance to a force applied in the direction of its length, and tending to draw it asunder. This resistance is evidently proportional to the transverse section of the body, for the cohesion of two, three, or four times as many particles must be destroyed, if the area of the section is increased two, three, or four times. If a wire supports a certain weight, two such wires, or one of double size of the same quality, will support a double weight. Tenacity is not modified by length, except that the probability of casual defects increases with the length. Tenacity is measured experimentally by securing one end of the body to a fixed point, and hanging gradually increasing weights to the other, until it is broken. The breaking weight measures the absolute strength. To compare the strength of different bodies, we must assume a *unit of area;* the one usually chosen is one square inch. The following table gives the absolute strength of some of the more important bodies, expressed in pounds for one square inch area of the transverse section.

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99. What is meant by strength of materials? 100. What is meant by the absolute strength of a body? How is tenacity measured?

1st, METALS:—

Steel, untemp.,	110,690—	127,094
“ temper'd,	114,794—	153,741
“ cast,	134,256	
Iron, bar,	53,182—	84,611
“ wire,	58,730—	112,905
“ cast,	16,243—	19,464
Silver, cast,	40,997	
Cop'r, do.,	20,320—	37,380
Brass, do.,	17,947—	19,472
“ wire,	47,114—	58,931
Gold,	20,490—	65,237
Tin, cast,	4,736	
Zinc,	2,820	
Lead,	,887—	1,824

2d, WOODS:—

Sycamore,	9,630	
Birch,	12,225	
Elm,	9,720—	15,040
Larch,	12,240	
Oak,	10,367—	25,851
Box,	14,210—	24,043
Ash,	13,480—	23,455
Pine,	10,038—	14,965
Fir,	6,991—	12,876

3d, CORDS:—

Hemp	twisted,	½ to 1	inch,	8,746
“	“	1—3	“	6,800
“	“	3—5	“	5,345
“	“	5—7	“	4,860

Wrought metals are more tenacious than cast, and alloys are sometimes stronger than either of their constituents. The strength of metals diminishes as they are heated; and sudden, frequent, and extreme changes of temperature always impair it.

Woods are subject to great inequalities. Trees grown on mountains are much stronger than those of the same kind from the plains.

The strength of cords is in proportion to the fineness of the strands, and also to the fineness of the flax or hemp-fibres of which the strands consist. They are weakened by overtwisting. Damp hempen cords are stronger than dry ones, twisted than spun, tarred than untarred, and unbleached than bleached. Silk cords are three times stronger than those of flax.

Animal and vegetable substances, converted from the liquid to the solid state, as gums, varnish, glue, &c., possess extraordinary strength. Rumford found that a solid cylinder of paper, glued together, whose sectional area was one square inch, would support 30,000 lbs; and a similar cylinder of hempen strings, glued together, lengthwise supported 92,000 lbs—a tenacity greater than that observed in iron.

101. **Resistance to pressure.**—The resistance of a column to a vertical force which tends to crush it, depends on its form, its sectional area, and its height. Of two columns of the same material, having the same form and equal heights, the one which has

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Mention the comparative strength of a number of the metals. Of the woods. What is said of wrought metals and the effect of temperature? What of the resistance of cords? Mention Rumford's experiments. 101. What does the resistance of a column to pressure depend upon?

the larger sectional area will be the stronger, but the exact ratio of increase is unknown.

According to Euler, when the base remains the same, the strength of a column diminishes as the square of the height; that is, when the height is trebled, the strength is diminished nine times. The resistance of a right prism is in the inverse ratio of the square of the height, and directly as the width, and the square of the thickness. A prism, whose base is a parallellogram, has less strength than one of the same height and volume, whose base is a square; and the latter less than a cylinder of equal height and volume. A solid cylinder resists less than a hollow one of equal height and mass; and lastly, a solid cylinder less than an equivalent cone. A column of one piece is stronger than one composed of several. Solids do not offer the same resistance in all positions; stones in the position of their natural bed are stronger than when placed otherwise; and wood is stronger in the direction of its fibres than across them. The strength of rectangular columns is directly as the product of the longer side of the section into the cube of the shorter side, and inversely as the square of the height.

102. **The lateral or transverse strength** of materials is their power to resist a force applied at right angles to their length, and tending to break them. Bodies subjected to a transverse strain are supposed to be prismatic or cylindrical beams and bars, whose cross sections are all equal and similar figures. They may be fixed at both ends and loaded in the centre, or supported at one end only, and have the weight at the other; in either case the breaking weight is the measure of the lateral strength. The *length* of the beam is the distance between the point of support; or, if one end only is supported, the distance from the weight to this point.

Both theory and experiment lead to this result, that if a rectangular beam of uniform thickness is supported at both ends and loaded in the centre, its *lateral strength* will be directly as the product of its breadth into the square of its depth, and inversely as its length.

What does Euler remark of columns whose base remains the same? Of right prisms? Of prisms whose base is a parellellogram? What of hollow cylinders? What of stone and wooden columns? 102 What is meant by transverse strength? How are beams experimented upon? What results are arrived at by theory and experiment?

Let W represent the lateral strength of any beam, b the breadth, d the depth of the end, and l the length; then

$$W = f\frac{d^2 b}{l}$$

If the beam is supported at one end only, and the weight applied at the other, we shall have

$$W' = f\frac{d^2 b}{4\,l}$$

In both formulæ, f represents the lateral strength of a beam of the same material whose sectional area is one square inch, or whatever unit of area may be chosen.

The following table gives the transverse strength of beams expressed in pounds for each square inch of area.

1st, METALS :—*	
Malleable Iron, . . .	17,800
Cast Iron, ...	15,300
Bass, ...	6,700
2d, WOODS :—†	
English Oak, ...	4,714
" "	6,688
Larch, ...	4,596
Canadian Oak, . . . , .	7,064
Ash, ...	8,004
Beech, ...	6,224
Elm, ...	4,052
Pitch-pine, ...	6,528
New England fir, ...	4,408

On account of irregularities of texture it is unsafe in practice to assume the strength of beams to be more than ⅔ of that assigned in the table. The formulæ before given will then be.

$$W = \tfrac{2}{3} f\frac{d^2 b}{l} \quad \text{and} \quad W' = \tfrac{1}{6} f\frac{d^2 b}{l}$$

If the weight is evenly distributed over the whole beam, it will support twice as much as if the whole pressure were placed in the centre. If a rectangular beam has two or three times the breadth of another, the depth and length being the same, it will have two or three times the lateral strength; and if the length is increased two or three times, other things being equal, the power of suspension will be diminished ½ or ⅓ respectively. When the length and breadth remain the same, the strength increases with the depth, but in a higher proportion. A beam having the same length and breadth as another, but twice or three times the depth, will bear a four or nine times greater weight. A thin board or beam is therefore much stronger when placed on its edge than on its side; on this principle, the rafters and floor timbers of buildings are made.

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* Tredgold. † Barlow.

What are the formulæ of the lateral strength of bodies? Give the transverse strength of the metals. Of the different woods. What is said of the distribution of the weight over a beam? What of rectangular beams? What is said of beams of double or treble the depth of another, but otherwise equal?

In round timber, the power of suspension is in proportion to the cubes of the diameters, and inversely as the length; a cylinder whose diameter is two or three times greater than that of another, will carry a weight 8 or 27 times heavier. The lateral strength of square timber is to that of the tree whence it is hewn as 10: 17 nearly.

A hollow cylinder is the form which combines the least weight of materials with the greatest lateral strength. Galileo was the first who remarked that the bones of animals, the quills of birds, the stalks of plants which bear a heavy weight of seed at their summit, and other similar hollow cylinders, offer a much greater resistance than solid cylinders of the same length and constructed of the same quantity of matter.

103. **Limits of magnitude.**—The materials of all structures must support their own weight, and therefore their available strength is the *excess* only of their absolute strength above what is necessary to support themselves. When *all* the dimensions of materials are increased, the absolute strength augments as the square of the ratio of increase, but at the same time, the weight of the materials augments as the cube of the increase. If the dimensions of a beam are doubled, it is four times stronger, and eight times heavier; or if its magnitude is multiplied 4 times, its strength will be multiplied 16 times, and its weight 64 times. In consequence of unequal ratio in increase, the strength of a structure of any kind cannot be estimated from its model, which is always much stronger in proportion to its size. In enlarging a structure, a limit is soon reached at which it has no available strength, its total absolute strength being required to support itself; and if this limit is passed, it will fall to pieces by its own weight. All works, natural and artificial, have such limits of magnitude which they cannot surpass while their materials remain the same.

In conformity to this principle, small animals are stronger than

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What is said of round timbers? What of square timbers? What of hollow cylinders? 103. What is the available strength of a structure? What is said of the absolute strength when all the dimensions of the material are increased? What of the strength of a structure and its model?

large ones, and insects and animalculæ are capable of feats of strength and agility, which seem miraculous when translated into the proportions of man. The operation of the same law may be seen by comparing the unwieldy movements of the elephant with the lithe and active tiger, or the easy motion of song-birds, and the arrowy swoop of the hawk, with the laborious and measured flight of the swan, and the condor of the Andes. For the same reason, the gigantic saurians, whose bones are mentioned by geologists, had their home in the ocean, where, in modern times, are found sea-weeds of interminable length, and animals, whose ponderous mass would be incapable of motion, if they were not floated buoyantly by the element they inhabit.

Adhesion of Solids.

104. **The molecular attraction** which holds together the particles of a solid, will also unite more or less firmly separate masses when their surfaces are brought into very close contact, and it is then called *adhesion.* (§34.) Since the effects of this force obtain equally in a vacuum, it must be independent of atmospheric pressure. To ascertain its amount experimentally, the adhering surfaces are placed in a horizontal position, and the lower one being fixed and the upper one attached to the arm of a balance, weights are put in the opposite scale, and the weight which separates them is the measure of their adhesion. The adhesive force for each square inch is found by dividing the surface by the weight.

Examples of adhesion are of familiar occurrence. The particles of chalk, charcoal, lead-pencils, &c., adhere to the surfaces written upon, and dust clings to the ceilings and walls, in opposition to the force of gravity. Two masses of lead, if their surfaces are smoothly cut, adhere almost as firmly as if they were one mass. A more striking instance occurs in manufactories of plate-glass. After the plates of which mirrors are made are polished, they are laid on their edges reclining against each other, and their surfaces are sometimes found adhering so strongly, that they cannot be separated without breaking. Some specimens from St. Gobin were united as firmly as if they had been melted together; they could be cut with a diamond,

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What is said of the strength of small animals and birds? What is said of the saurians, &c.? 104. What is adhesion? How is adhesion determined? Give some examples of adhesion. What is said of masses of lead? What of plates of glass?

and their edges polished, as if but a single plate; and by a force sufficient to make them slide, they were torn, so that the surface of one was covered with flakes detached from the other.

Adhesion occurs not only between surfaces of the same, but also of different kinds. In the process of silvering mirrors, metal is made to adhere to glass. A plate of tin and of lead, or of copper and of silver, unite into an almost inseparable whole, when their polished surfaces are pressed together with heavy rollers.

This kind of adhesion is most strongly manifested, when two surfaces are connected by a soft or fluid substance which solidifies in drying.

In this manner, stone and brick are built into firm and solid walls; and in the various processes of pasting, glazing and cementing, two solids may be so firmly united as to break anywhere else sooner than at the joint.

Adhesion has a considerable share in the resistance of *friction*, which will be explained hereafter.

Statical Forces or Pressures.

105. **Equilibrium.**—When all the forces acting on a body are mutually balanced by each other, or by resistance, it is in equilibrium. A body suspended by a thread is in equilibrium, because its gravity is balanced by the resistance of the thread and the point of support. There may be equilibrium without a fixed point of support and apparent resistance. A balloon in the air, and a fish in the water, are examples; but the weight of the fish and balloon are balanced by counteracting forces, to be explained in subsequent chapters.

106. **Forces which produce equilibrium** are called *statical* forces, or *pressures*, to distinguish them from *dynamical* forces, or those which produce motion. This distinction is artificial, and the student must not suppose that these are different *kinds* of forces. The same force may produce, according to circumstances, either pressure or motion.

To determine a force with precision, it is necessary to know to what point it is applied, its intensity, and its direction. The in-

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What is meant by heterogeneous adhesion? Mention examples. When is it most strongly manifested? Give an example. 105. When is a body in equilibrium? 106. What are statical forces?

tensity of statical forces can be compared only with each other, but their ratio may be represented by the ratio between other quantities, however different from them in kind. It is customary to represent pressures by equivalent weights, because weight is that sort of force with whose intensity we are most familiar. The units of pressure are familiarly expressed in *ounces*, *pounds*, *&c.*

Like other magnitudes, forces may also be represented by lines of definite lengths. Any line being chosen as a unit to represent the unit of pressure, the length of the line will represent the magnitude of the force, its direction will represent the direction of the pressure, and its commencement will show the point at which the force acts; by a line, therefore, a force is completely defined in all its three elements. In this way statical forces are brought within the limits of arithmetic, geometry and mathematics.

107. **System of forces.**—Whatever may be the number and direction of forces acting upon one point, they can impart motion or pressure in only one direction. We therefore assume, that there is a single force which can produce the same action as the system of forces, and may replace them. This is called the *resultant*, and the forces to whose effect it is equivalent, are termed the *components.* The components and resultant may be interchanged without changing the condition of the body acted on, or the mechanical effect of the forces themselves.

If two or more forces act in the same direction, the resultant is equal to their sum; if they act in opposite directions, the resultant is equal to their difference; and when the resultant equals nothing, equilibrium is produced. If a point is pressed upwards with a force of seven pounds, and downwards with a force of three pounds, the resultant is an upward pressure of four pounds.

108. **The parallellogram of forces,** is the construction employed to find the resultant of two forces which make an angle with each other. When the components are equal, the resultant bisects the angle between them; and if they are unequal, it is nearer the greater. Since the resultant is equal to the sum of the

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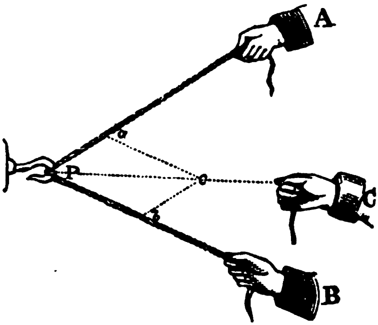
What is necessary in order to determine a force with precision? What are the units of pressure? How may force also be represented? 107. What is said of a number of forces acting on one point? What is the resultant? 108. What is the resultant when two or more forces act in the same direction? What when they act in opposite directions?

forces which coincide, and to the difference of those which exactly oppose each other, in all intermediate positions it will be less than their sum and greater than their difference.

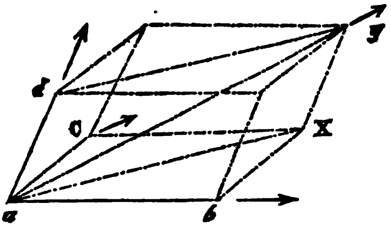
78



Let the point *P*, fig. 78, be acted on by two forces in the directions *PA* and *PB*. On *PA*, measure *Pa*, containing as many units of length (inches) as the force *A* contains units of pressure, (lbs.); and on *PB* take *Pb* in the same manner. Complete the parallellogram *Pacb*, and the diagonal *Pc* will represent the direction of a single force *C*, equivalent to the combined effect of *A* and *B*, and *P c* will contain as many units in length as *C* contains units of force.

109. **Any number of forces** acting on one point may be compounded in the same manner. Let the point *a*, fig. 79, be subjected to the pressures whose magnitudes and directions are represented by the line *a b*, *a C*, and *a d*. We first take any two which lie in the same plane, as *a b* and *a C*, and find their resultant *a X*; and compounding this with the third force *a d*, we find *a y*, which will represent the magnitude and direction of the general resultant of all three pressures. The resultant of any number of pressures in the same or different planes, may be found in the same way, by combining two at a time.

79



Give an illustration. 108. What is the parallellogram of forces? What is the resultant when the components are equal? What when unequal? What will the resultant be, compared with the original forces? Give the illustrations mentioned. 109. Give the illustration showing how any number of forces may be compounded.

110. **The resolution of forces,** is the converse of their composition. Since two or more forces can be replaced by a single force, so commonly, we may substitute two or more forces for one; and since an infinite number of systems may have the same resultant, conversely, one force may be replaced in innumerable ways by a system of several forces. But if one of two required components is given in magnitude and direction, there can be but one solution, and the problem is definite.

When a force acts upon a body at any other than a *right* angle, a part of its effect is lost. By resolving such an oblique force into two, one parallel, and the other perpendicular to the body, the latter component will represent the actual force produced. Let *a b* (fig. 80) represent a force acting under the angle *a b c* against the surface *M N*. Resolve *a b* into *a c* perpendicular to *M N*, and *a d* parallel with it; then *a c* will be the absolute effect of the force, and *a b*—*a c* is the loss.

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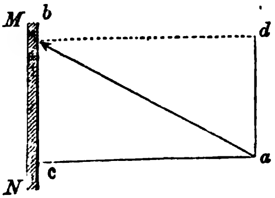
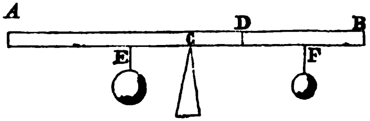


111. **Parallel forces. Resultant of unequal parallel forces.**—Two forces, acting side by side, produce the same effect as if they were in the same straight line. Two horses drawing a cart is an example. Hence the resultant of two parallel forces acting in the same direction is equal to their *sum* and is parallel to them, and when they are *equal*, is applied midway between them.

If the parallel forces are *unequal*, the point of application of the resultant may be found by the following experiment. Let *A B*, (fig. 81,) a bar of uniform thickness and density, be balanced on its centre *C*. We may suppose the bar to be divided into two, *A D* and *D B* of unequal lengths, which might also be balanced

81



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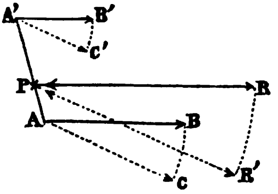
110. What is said of the resolution of forces? What of a force acting at other than right angles? How may the actual effect in such a case be found? 111. What are parallel forces? How is the point of application of the two parallel and unequal forces found?

on their centres *E* and *F*. Now we have two parallel and unequal forces—the weight of *A D* and the weight of *D B*—whose resultant is not midway between their points of application *E* and *F*, but passes through *C* which is nearer *E* than *F* in the exact ratio that the force at *E* exceeds that at *F*; for the weights of the two bars are as their lengths, and *C E* measures half the length *D B*, and *C F* half the length of *A D*; so that *C E* is to *C F* *inversely* as the weight at *E* is to the weight at *F*. The truth of this conclusion may be tested by suspending at *E* and *F* two additional weights which have the same ratio to each other as *A D* to *D B*, and the equilibrium will be undisturbed.

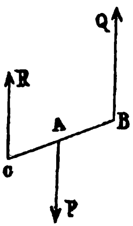
82



Hence the resultant of two parallel but unequal forces is equal to their sum, and its distances from them are inversely as their intensities. Thus in figure 82, if any two parallel forces act at *A* and *A'*, and their intensities are expressed by *A B* and *A' B'*, then their resultant will be represented by *P R*, provided it acts at *P*, a point so situated that *P A'* : *P A* :: *A B*: *A' B'*. The same will be true whatever be the common direction of the forces; if the positions of *A B* and *A' B'* are changed to *A C* and *A' C'*, then *P R* must move to *P R'*, and equilibrium equally obtains.

112. Resultant of two parallel forces acting in opposite directions.—The resultant of two parallel forces, which act in opposite directions, is found by the same construction as before, but it is equal to the *difference* of the components, and takes the direction of the greater. Its point of application, fig. 83, is in the prolongation of the line *A B*, at the point *C*, situated so that *C B* and *C A* are in the inverse ratio of the forces *Q* and *P*. The point *C* will be further removed as the difference between the forces *P* and *Q* are diminished, so that if the forces were equal, the resultant would be nothing, and situated at an infinite distance.

83



How may the truth of this conclusion be proved? What is the resultant of two parallel but unequal forces? How may it be demonstrated?

Thus whenever a body is solicited by two forces which are equal, parallel, and acting in opposite directions, it is impossible to replace them or produce equilibrium by a single force. Such a system of forces is called a *couple*, and its tendency is to produce revolution around an axis.

The general resultant of any number of parallel forces may be found by compounding them, successively, two by two, in the methods already prescribed.

113. **Two forces not parallel and applied to different points** may have a resultant, if they lie in the same plane. It is found by extending the lines of direction until they intersect. But if the forces are not parallel and lie in different planes, then the directions, though infinitely prolonged, will never intersect, and they cannot have any single resultant, or be in equilibrium by any single force.

Dynamical Forces, or Motions.

114. **Motion.**—When statical forces or pressures cease to be balanced, the body on which they act is set in motion. Absolute motion is a real change of place in space; relative motion is a change of the position of a body in reference to others which are considered as fixed, but which may be themselves in motion. Absolute motion is unknown to us. All the motions which we can determine are only relative.

Such are the motions on the earth, described with reference to points on its surface considered as fixed; but these points are constantly in motion around the sun, and our planetary system appears to be itself moving through space.

115. **Variations of motion.**—There may be the following variations in the motions of a body:—

a—The whole body may change its place and not return to it; this is *direct* motion. It is exhibited in projectiles, &c.

b—A body, as a pendulum, may change its position and return to it in an opposite direction; this is *vibrating* or *oscillating* motion.

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112. What is the resultant of two parallel forces acting in opposite directions? Give the demonstration. What is a couple? How may the general resultant of several parallel forces be found? 113. What is the resultant of two forces not parallel applied at different points? When not in the same plane? 114. What is absolute motion? Is it known? Give examples of relative motion.

c—The different parts of a body may at the same time move in different directions; this is called *rotation*. Instances are the daily rotation of the earth, the revolution of wheels, &c.

The direction of motion is represented by a straight line drawn from the point where motion commences, to the point towards which the body is propelled. The direction is *rectilinear*, when it is constantly the same, and *curvilinear*, when it varies every moment.

116. **Velocity** is the space traversed in a unit of time, or the constant relation existing between the space traversed and the time when the body has a uniform motion, that is, when it traverses equal spaces in equal times. Velocities, like any other magnitudes, are compared with each other, and their ratios may be represented by the ratios of lines and numbers. There is no established unit of velocity, distinguished by a particular name, like feet, and pounds, and the units of length and pressure. To express velocity in numbers we must use the units of time and length. If a number only were employed, without naming the units taken, the velocity would be wholly indefinite. The simplest mode is to give the space traversed in a unit of time, which in Physics is generally the second.

For example: a man usually walks with a velocity of 2½ feet in a second. An ordinary wind has a velocity of 3½ feet, and a hurricane 118 feet in a second.

Velocities admit of comparison only when they are expressed in the same units.

117. **Variable motion.**—When a body does not pass over equal spaces in equal times, however small they may be, the motion is variable. In this case, the velocity in any given instant, is the relation between the space traversed and the time, when the time is infinitely small; or the space traversed in a unit of time, supposing that the motions were uniform, at that instant.

118. **Uniformly accelerated or retarded motion.**—A motion is uniformly accelerated or uniformly retarded, when the velocity increases or diminishes equally in equal times. In both cases the distinction must be observed between the body's *initial* and

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115. What is said of the different varieties of motion? How is the direction of motion represented? What is rectilinear and curvilinear motion? 116. What is velocity? How is velocity expressed? What is the unit of terms employed? Give examples of comparison of velocities. 117. What is variable motion?

final velocity—that with which the body begins, and that with which it ceases to move.

Let V represent the velocity, D, the distance, and T, the time; then, in uniform motion,

$$V = \frac{D}{T}$$

$$D = V \times T$$

$$T = \frac{D}{V}$$

119. **Composition and resolution of motion.**—Since forces which produce pressure would produce motion in the direction of the pressure, if the bodies on which they act were free to move, all the principles of the composition and resolution of pressure, are equally applicable to motions. This important application could not be made, however, were it not for the physical law, that the *dynamical effects of forces are proportional to their statical effects.* A force which produces twice as much pressure as another, will also produce twice as much motion; that is, it will either impart; (*a*) to *twice* as much matter the *same* velocity in the *same* time; (*b*) or to the *same* matter *twice* the velocity in the *same* time; (*c*) or to the *same* matter the *same* velocity in *half* the time. This is not an abstract truth, but a law of nature, which could be learned only by experiment. The rules for the composition of pressures may be deduced without any appeal to nature; but such an appeal is necessary before we can apply them to motions, for they could not be applied if pressures did not produce proportional motions. The dynamical effects of forces might have been as the squares of their statical effects, or the reverse; a double pressure might have produced a quadruple motion, or a quadruple pressure a double motion; and in neither case could they be compounded in the simple manner explained.

When several forces act on a body, they may be arranged in three ways, according to their direction. The forces may act,

(*a*)—all in one direction;
(*b*)—or in exactly opposite directions;
(*c*)—or at some angle.

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118. What is said of uniformly accelerated or retarded motion? Give the formulæ for velocity, distance and time in uniform motion. 119. What is said of the composition and resolution of pressure and motion? What is the physical law mentioned? Mention the illustrations *a, b, c.* What is said of the necessity of experiment to determine this law?

In the first case, the resultant is the sum of all the forces, and the direction is unaltered. In the second, the resultant is the difference of the forces, and takes the direction of the greater. If opposite forces are equal, the resultant is nothing, and no motion is produced. In the third case, a resultant is found to two forces, whether equal or unequal, by the parallelogram of forces, according to the following law. *By any number of forces acting together for a given time, a body is brought to the same place as if each of the forces, or one equal and parallel to it, had acted on the body separately and successively for an equal time.*

Suppose two forces act simultaneously on the point *a*, fig. 84, one in the direction *a x*, and the other in the direction *a y*. Let one force be such that, in a given time, as a second, it will move the point from *a* to *b*, while the other will, in the same time, move it from *a* to *c*, then by the joint action of both forces it will be impelled to *r* in the same time. The first force, by its separate action, would impel the body to *b* in one second, and if it were then to cease, the second force, or one equal and parallel to it, would impel to *r* in the same time; or the body might be carried from *a* to *c*, and from *c* to *r*; in either case the result is the same.

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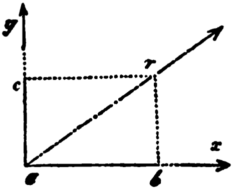

In the same manner a resultant may be found for three or any number of motive forces, by compounding them, two by two, successively.

In order that the body may move in the straight line *a r*, the two forces must act in the same manner. They may be instantaneous impulses, which will cause uniform motion; or both may act continuously and uniformly, so as to produce a uniformly accelerated motion; or, both forces may act with a constantly varying intensity, increasing or diminishing at the same rate, and the body will still move in a straight line. But if one force is instantaneous and the other constant, or one constant and the other variable, or both varying by different laws, then the body will move in a curve; but in every case it will reach the point *r* in the same time that it would have passed from *a* to *b*, or from *a* to *c*, by the separate action of either force.

When several forces act on a body, how may they be arranged? What is the resultant in each case? Give the illustration. What is said of the manner in which these forces must act? If they act variably in time what is the result?

120. **Examples of the composition of motion** are of constant and familiar occurrence.

A man in swimming, impels himself in a direction perpendicular to his feet and hands, and if the forces are equal on each side he will move in a resultant line, passing through the centre of his body. Another instance is the flight of birds. While flying, their wings perform symmetrical movements, and strike against the air with equal force.

In the case of flying birds the resistance of the air is perpendicular to the surface of the wings, and may be represented, fig. 85, by *C A* and *D A*, at right angles to their surface. Neither of these pressures tends to impel the bird straight forward, but it moves in their *resultant;* for if the wings are equally extended, and act with equal force, the lines *C A*, and *D A*, make equal angles with *A B*, passing through the centre of the bird, and hence their diagonal, or *A G*, the diagonal of equal parts of them, will coincide with *A B*, and the bird will fly directly forward.

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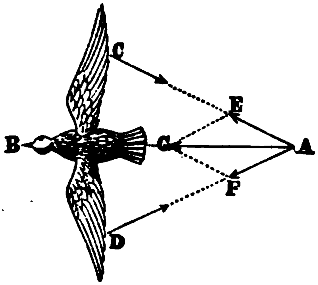

121. **Resolution of motion.**—The motion of a boat impelled by oars is similar to the examples just cited; but when sails are used, and the force of the wind is transmitted from them to the keel, and modified by the rudder, we have an example of the resolution of motion.

Let *a b*, fig. 86, represent the length of a vessel, *m n* the sail supported against the mast at *o*, and *o p* the magnitude and direction of the wind. Construct the parallelogram *o p e d*, of which *o p* is the diagonal. The force *o p* may be resolved into two forces, of which the first, *o c*, is parallel to the sail, and produces no pressure upon it; and the second, *o d*, is perpendicular to the sail, and represents the whole pressure of the wind. But *o d* may be resolved into two other forces; the one, *o f*, at

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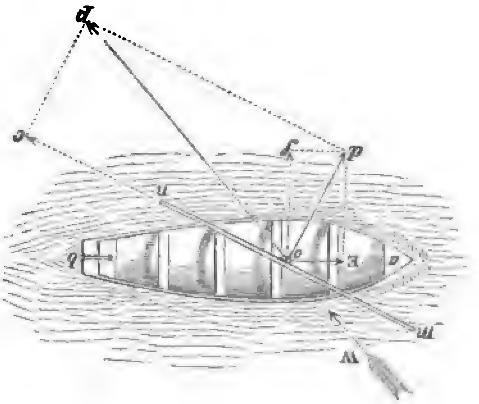
120. Give the examples of composition of motion. Describe fig. 85. 121. What is said of a sail-boat? What of the resolution of motion in this case?

right angles to the keel, urges the vessel sideways ; the other, *o E*, in the direction of the vessel's length, tends to advance it, and represents the whole *effective* force of the wind. By a skillful application of the principles of the resolution of motion, a vessel may be sailed on a course, within five or six points of being directly opposed to the wind which impels it.

86



122. **Common motion not interfering with particular motion.**—In connection with this subject it is important to notice, that a motion common to all bodies of a system, does not at all interfere with the particular motions of any one of them, but such motions continue as if the system was at rest.

If a bullet is dropped from the mast-head of a ship sailing ever so rapidly, it will fall to the deck on precisely the same spot as if the ship were motionless. A watch is carried without deranging the delicate movement of its works. The earth moves on its axis at the rate of a thousand miles an hour at the equator, without interfering with the motions on its surface, except in case of the trade winds, and a few similar instances of composition of motion.

Impact of Solid Bodies.

123. **Transfer of force.**—When a force acts on a body, it produces

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122. What is said of a common motion not interfering with a particular motion? Give examples.

its effect as soon as motion is diffused among all the molecules, and the force is then transferred from the moving power, into the substance of the thing moved. In consequence of the inertia of matter, if the moving body meet no resistance, and no other force acted upon it, it would continue to move with the same velocity, and in the same direction, forever.

124. **Relation of velocity to quantity of matter.**—Since a body absorbs, as it were, the force acting upon it, we can easily understand what our experience confirms, that the same force acting upon different bodies, produces very different motions.

A charge of powder sufficient to project a bullet, would scarcely stir a cannon ball. The reason commonly assigned, is, that the ball is heavier than the bullet; but if their gravity, and all the resistances to motion were removed, the bullet, under the same impulse, would still move as much faster than the ball as its quantity of matter was less.

It is a fundamental principle of mechanics, that the same force acting upon different bodies, imparts velocities in the *inverse* ratio of their quantities of matter. If the same force successively projected balls, whose masses were as the numbers 1, 2, 3, &c., it would impart to them the velocities 1, $\frac{1}{2}$, $\frac{1}{3}$, &c., so that a mass ten times larger, would acquire a velocity of only $\frac{1}{10}$. The product of each of these masses into its velocity, is the same, for $1 \times 1 = 1$, $2 \times \frac{1}{2} = 1$, &c.; and this product of the mass into the velocity of a body, is called its *momentum*, *moving force*, or *quantity of motion*.

125. **Momentum, velocity.**—Momentum must not be confounded with velocity, which is the *intensity* of a motion, not its *quantity*. The same force always produces the same momentum, whatever may be the body on which it acts, so that the measure of an impact, is the momentum it imparts.

We may describe an impact by saying, that it is equal to 20 lbs. moved one foot a second, or 1 lb. moved 20 feet a second, or 2 lbs. moved 10 feet a second; the momentum being in each case the same.

126. **Laws of momentum.**—It follows, therefore, that

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123. What is said of the transference of force when a force acts on a body? 124. Give examples showing relation of velocity to quantity of matter. What is stated to be a fundamental principle of mechanics? What is momentum? 125. What is velocity? How may we describe an impact?

a—When the masses are equal, the moments are proportional to the velocities.

b—When the velocities are equal, the moments are proportional to the masses.

c—When neither the velocities nor masses are equal, the moments are proportional to the *product* of the masses and velocities.

From these laws it will be easily seen why great masses, as loaded ships, icebergs, &c., though they move but slowly, exert such crushing force upon objects with which they come in contact; and also why cannon and musket balls, in consequence of their great velocity, are so destructive.

127. **Impact.**—When a body in motion encounters another, the velocity and momentum of both undergo certain changes, which depend on the elasticity of the bodies, and other physical circumstances.

a—When a body in motion strikes another at rest, it can continue to move only by pushing this body before it, and it must impart so much momentum, that after impact, both may move with a common velocity. If the masses of the two bodies are equal, it is evident that after impact, the momentum will be equally divided between them, and their velocity will be one half of the velocity of the moving body before collision. If the mass at rest is double the mass in motion, the common velocity will be one third; and generally, when a moving body communicates motion to a body at rest, the velocity of the two united, will be to that of the moving body as the mass of the latter is to the sum of the masses of both.

If a musket ball, whose weight is $\frac{1}{20}$ lb. and its velocity 1300 feet a second, strikes a suspended cannon ball weighing 48 lbs., it will put it in motion, and their common velocity will be to that of the bullet as $\frac{1}{20}$ is to $48 + \frac{1}{20}$, or as 1 is to 961; the velocity of the two is therefore $\frac{1300}{961}$, or about $1\frac{1}{3}$ feet a second.

b—Bodies moving in the same direction may impinge, if their velocities are different. If an inelastic body overtakes another, the first will accelerate the second, and the second will retard the first, until they have acquired a common velocity, when they will

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126. Mention the laws of momentum. What is said of ice-bergs and musket balls? 127. What follows when a body in motion strikes another at rest? When the masses are equal? When the mass at rest is double the mass in motion? Give the example in illustration. What is the effect when an inelastic body overtakes matter?

move on together. Since the bodies move in the same direction, there can be no increase or diminution of the total momentum by impact, but only a re-distribution. If they are equal in mass, their velocity, after impact, will be half the sum of their previous velocities.

If before impact, *A* had a velocity of 6, and *B* a velocity of 4, then their common velocity will be 5.

The two bodies may have unequal masses as well as velocities.

If the mass of *A* is 8, and its velocity 17, its momentum will be 136. If *B* has a mass of 6, and velocity of 10, its momentum will be 60. The sum 196, which is the total momentum of the united masses after impact; and the sum divided by the sum of the masses, gives 14, the common velocity.

c—If two equal bodies, moving with equal velocities in opposite directions, impinge on each other, their moments being equal, will be mutually destroyed, and the bodies will remain at rest. The force of the shock, in this case, is equal to that which either would sustain, if, while at rest, it were struck by the other with a double velocity. If the moments of the bodies are unequal, then, after impact, they will move together in the direction of the greater, and their joint momentum will be equal to the difference of their previous moments, and their velocity will be found by dividing that difference by the sum of the masses.

d—These laws may be shown experimentally, by suspending two balls at the centre of a graduated arc, and producing impact according to the conditions described.

If two bodies moving in different lines impinge on each other, then, after contact, they will move together in the diagonal of that parallelogram whose sides represent their previous moments and directions.

128. **Vis viva.**—If the body impinged on is immovable, or very large, compared with the moving body, no motion will ensue, and the collision will affect only the point of impact. The effects, (and in case the body at rest is penetrated by the

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Illustrate what happens when the two bodies have unequal masses as well as velocities? What is the effect when equal bodies moving in opposite directions with equal velocity impinge? What is the force of the shock? What is the effect if they are moving with unequal momentum? How may these laws be illustrated?

other,) the *depths penetrated*, are as the *squares* of the velocities multiplied into the mass of the projectile.

If two unequal balls, as a six and twelve pounder, have velocities inversely as their masses, their moments will be equal; both will move and overturn the same obstacle, but they will not penetrate a body to the same depth, for both will overcome resistance for the *same time*, and during that time the swifter ball will penetrate twice as far as the other.

The penetrating effects of projectiles are equal, when their masses are *inversely* as the squares of their velocities, so that their moments multiplied into their velocities may be equal.

129. **Formula for projectile force.**—Beaufoy determined that a body of 1 lb. weight, with a velocity of 1 foot in a second, strikes with a force equal to 0·5008 lb. To find the force of impact of any projectile, we have the general formula,

$$F = 0.5008\ MV^2.$$

The motion communicated to very large or immovable bodies by an impact of small ones, is not lost, but becomes insensible from its enormous diffusion. Motion can be destroyed only by motion; friction and resistance disperse, but do not destroy it.

130. **Diffusion of motion requires time.**—An impact can act directly upon only a few of the molecules of the body to which it imparts motion.

The power which projects a bullet, acts on only one-half its surface.

The motion must, therefore, be diffused from the parts struck, to all the other parts of the body, before it can begin to move; and this diffusion requires *time*, which may be short indeed, but is not infinitely so. It happens, therefore, that a movable body, if struck by another moving with great velocity, may be penetrated or broken at the point of impact, without being itself put in motion. Such effects appear incredible to persons unacquainted with the inertia of matter, and its consequences.

A rifle ball may be fired through a pane of glass suspended by a thread, without shattering the glass, or even causing it to vibrate.

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128. What is the result when the body impinged on is immovable? What the effect when the body is penetrated? Mention the illustration. When are the penetrating effects of projectiles equal? 129. What is the general formula for projectile force? 130. What is said of the diffusion of motion requiring time?

A half open door may be perforated by a common ball without being shut by it. A soft missile, like tallow, or a light one, like a feather, will act with the force of lead, if sufficient velocity is given to it. Firing a tallow candle through a board is a well-known trick of showmen. In *ricochet* firing, a cannon ball, shot at an elevation of from 3° to 6°, rebounds from the surface of water, just as every boy has made flat stones skip from point to point on its surface. The recoil of a gun does not begin to be felt until the ball has left the mouth of the piece. The experiment in proof of this, was first performed at Rochelle, in 1667, by order of the Cardinal Richelieu. A cannon was suspended like a pendulum, from the end of a long shaft, and a ball shot from it struck precisely as it did when the cannon was fixed; but if it had begun to move before the ball was discharged, the point struck would have been lower, depending on the amount of recoil.

131. **The ballistic pendulum,** a large mass of wood or metal, suspended freely by a long shaft, is employed to measure the velocity of projectiles, on the principles of impact. (Fig. 87.) The ball is fired into the solid block of the pendulum, and the height to which it oscillates by the blow, is shown by an index on a graduated arc, and determines the velocity with which the pendulum began to move, when its momentum was equal to that of the ball.

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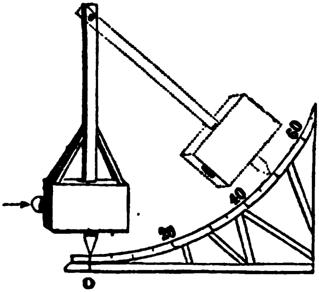

132. **Impact of elastic bodies.**—When collision takes place between perfectly elastic bodies, the loss of momentum sustained by each, is twice as great as in inelastic bodies. For when two elastic bodies strike together, the parts of each are compressed, and when this force ceases, the particles return to their original positions, and impart reciprocally an impact opposite to the former motion of each.

If the masses of two elastic bodies are equal, after impact, they will exchange both their directions and velocities.

Give examples in illustration. What was Cardinal Richelieu's experiment? 131. Describe the ballistic pendulum. 132. What is said of the impact of elastic bodies?

a—If both move directly towards each other, after collision, they will both recoil with inverse velocities.

b—If both move, with different velocities, in the same direction, after impact, they will continue in the same direction, but with inverted velocities.

c—If one body is at rest, after impact, the striking body becomes stationary, and the other moves on with the velocity of the impinging body.

These laws may be experimentally shown with ivory balls, in the following manner.

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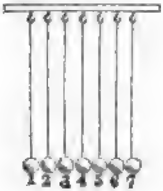

If several equal ivory balls are suspended, as in fig. 88, and the first is let fall on the others, the last only, No. 7, will move, and this starts with the momentum which No. 1 had at the instant of striking No. 2; again, No. 7 falling, will cause No. 1 to rise, and this alternate movement of the extreme balls of the series will continue, until destroyed by friction, and the resistance of the air.

133. **If an elastic body strikes an elastic plane,** it will recoil with a velocity equal to that of impact. If the impact is perpendicular, it returns in the same direction; if it is oblique, the body rebounds, under the same angle, in an opposite direction; or, as it is usually stated, the angle of *incidence* is equal to the angle of *reflection.*

134. **Newton's laws of motion.**—Before the principles of mechanical philosophy were well established, the property of inertia and its consequences were stated by Newton in three formulæ, called by him the *laws of motion,* which are so famous in the history of physical science, and formerly so important, that they ought to be remembered by every student.

1. *Every body continues in its state of rest, or of uniform motion, unless compelled to change that state by an external force.*

2. *Every change of motion is in the direction of the force impressed, and is proportional to it.*

When the two bodies are equal what is the result? What when one body is at rest? Mention the experiment with the ivory balls. 133. What is the result when an elastic body strikes an elastic plane? 134. What is said of Newton's laws of motion?

3. *Action and reaction are equal and contrary; or the actions of two bodies on each other are equal, and opposite in direction.*

The first law, is a definition of inertia.

The second, is strictly true only of a body at rest; for if a body already in motion is acted on by another force, or if two forces act together on a body at rest, then it will move in the direction of neither, but between them, according to the law of composition of forces.

The third, means nothing more than the equal interchange of momentum, in opposite directions, between bodies which come into collision.

Gravitation.

135. **Gravitation** is that universal force which all matter obeys, and which maintains the order and stability of the universe. The discovery of its laws was begun by Newton, in 1666, but not completed until June, 1682; when he received Picard's new measurement of the arc of a meridian, a quantity indispensable to his calculations.

The laws of gravitation may be stated as follows: *Every particle of matter, attracts every other particle in the* DIRECT *ratio of its mass, and in the* INVERSE *ratio of the square of its distance.*

That is, if the mass of one particle is 2, 3, or 4 times greater than the mass of another, its gravity is also 2, 3, or 4 times greater; and if the distance is 2, 3, or 4 times increased, the force of gravity is 4, 9, or 16 times diminished.

Let M and m represent the masses, D and d the distances, and G and g the forces of gravity of two particles, then

$$G : g :: M : m$$
$$\text{and } G : g :: d^2 : D^2$$

136. **Application of the theory of gravitation to astronomy.**—The announcement of these laws was one of those prime discoveries which mark and make an era in the history of science. For the future, it rendered impossible any retrograde movement,

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Mention the three laws. What is said of these three laws? 135. What is gravitation? When and by whom was it discovered? What are the laws of gravitation? Give the formulæ.

like that in which men lost sight of the true system of the world, once taught by Pythagoras. When the planetary forces and motions were shown to be identical with those existing at the earth's surface, astronomy rose from a science of mere observation, to the rank of an experimental science of number and quantity. Henceforth calculation predicted and verified the results of observation, and thus furnished, astronomy speedily became what it now is, the most perfect branch of Physical Philosophy. Previous to Newton's discovery, the various branches of mathematical and mechanical science had reached a point where they could advance no further, without some such principle to reduce them all into a connected system. The discoveries of the ancient geometers, the dynamical experiments of Galileo, the singular proportions observed by Kepler, in the motions of the planets, and the speculations of Hooke upon attraction, smoothed some of the first obstacles in Newton's path of discovery, and prepared a state of knowledge in which his master mind could effectually exert its powers. The axioms of dynamics were applied by him to the complete explanation of all the great and many of the minutest phenomena of astronomy. In doing this, he found the mathematics of his age insufficient, and he therefore invented the method of fluxions, or differential calculus, which, as a means of discovery, "bears the same proportion to the methods previously in use, that the steam-engine does to the mechanical powers employed before its invention."*

The consideration of the laws of gravitation, as applied to the elliptic motions of the planets, and their complex irregularities, to the cometary orbits, and the vastly remote systems of binary stars, belongs to celestial mechanics, or astronomy; we are here concerned only with less grand, but equally interesting phenomena, produced by the attraction of the earth upon small bodies, momentarily detached from its general mass.

137. **Terrestrial gravity.**—The laws of gravitation, in the abstract and general form in which they have just been stated, do not immediately apply to the attraction of the earth, or of the

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* Herschel's prelim. discourse.

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136. What is said of the announcement of these laws? What of mathematical science previous to Newton? What discoveries removed some of the obstacles in Newton's path of discovery? What application of the laws of gravitation were made by Newton.

other planets. They are not mere *particles*, but great spherical masses of matter. Newton, however, has demonstrated that a particle of matter, placed without a hollow sphere, is attracted in precisely the same manner as if the whole mass of the sphere were collected into its centre, and constituted a single particle there. The same must be true of solid spheres, since they may be considered as composed of an infinite number of hollow spheres, having the same centre.

138. **Form of the earth.**—Although the earth is described, in general terms, as spherical, it is not exactly so, but spheroidal, or compressed in the direction of its axis, so as to have some resemblance to the figure of an orange. This deviation is too small to affect the mutual attractions of the earth and planets, at the immense distances which lie between them; but it is considerable enough to cause irregularities in the motions of the moon, and in the weight and fall of bodies, at the earth's surface. According to Bessel,* the earth's equatorial, exceeds its polar diameter by nearly 26½ miles. (26·471.)

This difference is trifling when compared with the whole dimensions of the earth; in an exact model of 15 inches diameter, it would be only $\frac{1}{20}$ of an inch; a quantity too small to be detected by the most practised eye or hand.

139. **Local variations of the intensity of gravity.**—Weight is a particular instance of gravity, the *effect* of which the earth's attraction is the cause. If the earth were a perfect sphere, the same body would be equally attracted, and therefore have the same weight at every point on its surface: because a sphere is everywhere symmetrical; and the body would be everywhere equally distant from the centre. But a spheroid is not symmetrical in the same manner, and a body placed at its equator, and a similar one at its pole, stand in different relations to the whole mass, and the weight of either of them will be the greatest at the poles, and gradually diminish from thence to the equator, where it will be least. There is a latitude, intermediate between

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* Herschel's astronomy, page 135.

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137. What is said of terrestrial gravity? What has Newton demonstrated of the attraction of a hollow sphere? 138. What is the form of the earth? How may this trifling difference be illustrated? 139. What is said of the weight of a body if the earth was a sphere?

the poles, and the equator, where the earth attracts bodies on its surface, as if it were a sphere; and in that latitude, bodies fall fall through $16\frac{1}{12}$ (16·0697) feet in a second. Newton and others have determined that the difference of weight due to the elliptical form of the earth alone, is the $\frac{1}{596}$th part of the whole difference, which has been found, by repeated experiments, to be $\frac{1}{194}$th part of the total weight of the body. The large remainder, $\frac{1}{286}$th part, is due to the centrifugal force, produced by the earth's rapid rotation on its axis. This force, which is nothing at the poles, regularly increases from thence to the equator, where it is greatest, and in the same ratio diminishes the sensible gravity of bodies.

The same body is therefore *specifically lighter* at the equator, than at the poles of the earth, in the ratio of 194 to 195. This difference cannot be detected by the balance, because the thing weighed is counterpoised by an equal standard weight, under the same circumstances; and if both are removed to another station, their weight, if changed, will be changed equally, and a body and its counterpoise once adjusted, will continue to balance each other wherever they are carried. It is not in this sense, that 194 lbs. at the equator will weigh 195 lbs. at the poles; but if we conceive a body, y, suspended by a cord, imagined without weight, passing over a pully at the equator, as in the annexed figure, 89, and connected by other pulleys with x, another equal weight at the poles; then, although the weights would counterpoise each other in a balance, they would not in this situation, but the polar weight would preponderate, and y would require to be increased by $\frac{1}{194}$th part, to restore the equilibrium.

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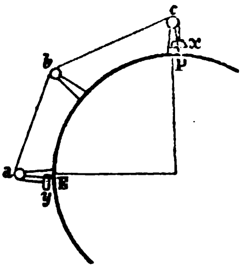

In consequence of the second law of gravity, the same body is less heavy on the top, than at the base of a lofty mountain, because it will be then further removed from the earth's centre.

What as the earth is a spheroid? What is the difference in weight of a body owing to the spheroidal form of the earth? Why cannot this difference be detected by the balance? How may this difference be illustrated? What is said of the weight of a body at different elevations above the earth's surface?

A body weighing 1000 lbs. at the earth's surface, loses 2 lbs. at an elevation of four miles, and at the distance of the moon, its sensible weight would be only five ounces.

When a body penetrates below the earth's surface, its sensible gravity is also diminished. Whatever part of the earth is above the body, attracts it towards the surface, while the mass below attracts it in the opposite direction, and the body tends towards the earth's centre, with the difference of these two forces.

Could a body be placed in an empty space, at the centre of the earth, it would be sustained there in equilibrium, without any material support, by the action of equal and opposite attractions.

140. **The direction of the force of gravity** is a vertical line, which, if produced, would pass through the centre of the earth. This position is always assumed by a *plumb-line*, (a weight freely suspended by a cord,) and a line or plane at right angles to it, is said to be horizontal. The direction of the vertical, is evidently different for each place, and since this direction determines the terms *up* and *down*, these expressions have only a relative meaning, and change, as the direction of gravity changes, in passing from one place to another.

Two plumb-lines, therefore, can never hang absolutely parallel, but, on account of the magnitude of the earth, their convergence is imperceptible within moderate distances. At greater distances, when miles intervene, the convergence of the perpendiculars must be estimated. Its amount is one minute in a geographical mile.

141. **Plumb-line in the vicinity of a mountain.—Estimation of the density of the earth.**—In the vicinity of a mountain, a plumb-line is not truly perpendicular, but drawn to one side by the lateral attraction of the mass. This deviation is measured by observations on the zenith distances of a star, at stations on opposite sides of the mountain, and on the same meridian. It was first noticed in 1738, by the French academicians engaged in measuring a meridian arc in Peru. In 1774, Maskelyne found a deviation of 5′ 8″, caused by the lateral at-

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What when a body penetrates below the earth's surface? What is said of a body at the centre of the earth? 140. What is the direction of the force of gravity? What is a horizontal line or plane? What is said of the terms up and down? What of the convergence of perpendicular lines? 141. What is the direction of a plumb-line in the vicinity of a mountain?

traction of Schehallien, a mountain in Scotland. The accurate investigation of this problem, was one of the highest importance in astronomy, since it furnished the means of determining the mean density of the earth, by comparing its attraction with the attraction of a part of its mass, whose density could be ascertained by direct experiment.

The same result is attained, with much greater precision, by the famous Cavendish experiment, in which the earth's attraction is compared with that of a mass of lead.

Cavendish's determinations of the density of the earth, were made by means of an apparatus suggested by the Rev. John Michell.

"Michell's apparatus was a delicate torsion balance, consisting of a light wooden arm, suspended in a horizontal position, by a slender wire, 40 inches long, and having a leaden ball about 2 inches in diameter, hung at either extremity. Two heavy spherical masses of metal were then brought near to the balls, so that their attractions conspired in drawing the arm aside. The deviation of the arm was observed; and the force necessary to produce a given deviation of the arm, being calculated from its time of vibration, it was found what portion of the weight of either ball, was equal to the attraction of the mass of metal placed near it. From the known weight of the mass of metal, the distance of the centres of the mass, and of the ball, and the ascertained attraction, it is easy to determine the attraction of an equal spherical mass of water, upon a particle as heavy as the ball placed on its surface. Now the attraction of this sphere, will have to that of the earth, the same ratio as their densities; and as the attraction of the earth is equal to the weight of the ball, it follows, that as the calculated attraction is to the weight of the ball, so is the density of water to the earth's density, which is thus determined." (Wilson's life of Cavendish.)

A comparison of about two thousand experiments with this delicate apparatus, conducted by Mr. Francis Bailey, determined the mean density of the earth to be 5·6604 times that of water. It is worthy of remark, that Newton, whose *guesses* were often worth more than the researches of less sagacious men, had conjectured the earth's density to be between 5 and 6 times the density of water.

How is the deviation from a perpendicular measured? By whom was the deviation first noticed? Of what importance is its accurate determination? Describe Cavendish's experiment. What is the mean density of the earth?

Centre of Gravity.

142. **Centre of gravity.**—The forces with which the earth attracts the molecules of all bodies at its surface, may, therefore, be considered parallel to each other, since they converge towards a point, the earth's centre, at an infinite distance, compared with the dimensions of the bodies. The number of these equal and parallel attractions is the same as the number of the molecules; but since there is in every body a point about which its molecules are equally distributed in all directions, all these attractions may be replaced by a single force, applied at this point, which is called the *centre of gravity* of the body, or the centre of equal and parallel forces. In solids, this is a fixed point, and does not change, whatever may be the position of the body itself; for, we have already seen, (§ 111,) that the point of application of the resultant of parallel forces, is independent of their direction.

143. **Experimental determination of the centre of gravity.**—When a body is freely suspended, it will remain at rest only when the vertical of the centre of gravity coincides with the direction of the cord of suspension; for two equal forces are in equilibrium only when they act in opposite directions. This consideration affords the means of finding the centre of gravity by experiment. If, therefore, any irregular solid is suspended, as in fig. 90, its center of gravity will lie in the line *c d*, prolonged through its interior. It will also lie in the line *a b*, by which the body is a second time suspended, and being found in both lines, it must necessarily be at their intersection.

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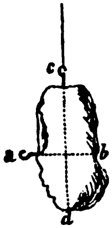

144. **Centre of gravity of regular figures.**—In case of solids which have a regular figure, and uniform density, it is not necessary to resort to experiment. In such bodies, the centre of gravity coincides with the centre of magnitudes, and to find it, is a question purely geometrical. The truth of this assertion may be shown, if we suppose a plane or line to be divided into two equal and similar parts, so that its molecules are arranged two by two, with respect to the dividing line. Take any two molecules similarly situated, on opposite sides of the di-

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142. What is the centre of gravity? 143. When will a body freely suspended remain at rest? How is the centre of gravity of an irregular figure determined? 144. What is said of the centre of gravity of a regular solid?

vision, their moments will be equal and opposite; and so also of every other pair; therefore, the resultant of the system must be at the point of division, and the centre of gravity is there also.

The centre of gravity of a circle, or sphere, is at the centre of each; of a parallelogram or prism, at the intersection of the diagonals; and of a cylinder, at the middle point of its axis. To find the centre of gravity of a triangle, fig. 91, draw a line *A D*, from the vertex to the middle point of the base; it will divide equally all the lines, as *m n*, drawn parallel to the base. If the triangle is placed so that the line *A D* may be exactly over the edge of the prism *P Q*, each one of the rows of molecules composing the figure, as *m n*, will be in equilibrium on the edge of the prism, since it is supported at its centre. The same will be true when they are united, and the triangle will not tend more to one side than another; hence its centre of gravity must be in the line *A D*, and for a like reason, also in the line *B E*, and therefore at their intersection *G*. It may be shown that the point, thus found, divides the line joining the summit, and the middle of the base, into two parts, of which the one nearest the vertex is double that nearest the base.

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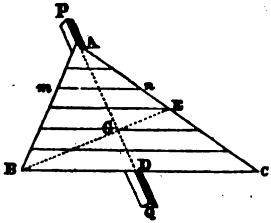

145. **Support of a triangular mass at its angles.**—If it were required to support a triangular block of marble at its angles, we may find what part of the weight will be sustained by each support, by applying the foregoing principles. The weight of the block, fig. 92, which we will suppose to be 45 lbs., is a force applied to its centre of gravity, *g*. We have seen that the distance *b g*, is twice the distance *g d*, and hence we may resolve the vertical force of 45 lbs., acting at *g*, into two others; one of 15 lbs. at *b*, and the other of 30 lbs. at *d*; but the last force, since it acts at the middle point of *a c*, may also be resolved into two others of

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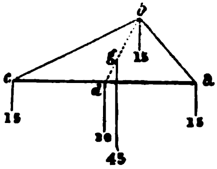
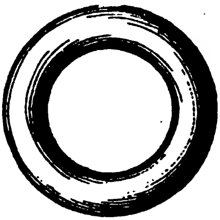


How may the truth of this be drawn? What is the centre of gravity of a circle or a sphere? How is the centre of gravity of a triangle found? 145. What is said of a triangular block of marble supported at its angles?

15 lbs. each, acting the one at *a*, and the other at *c*. Hence the weight of the triangle is equivalent to three equal forces acting vertically at its angles; and the three points of support sustain equal pressures, whatever may be form of the triangle.

146. **Centre of gravity lying without the body.**—The centre of gravity is not, necessarily, in the body itself, but may be in some adjoining space. This is evidently true of the solid ring, fig. 93, and generally of any hollow vessel, of whatever form.

93



Of a compound body, the centre of gravity is easily found by composition of forces, when the weights and centres of gravity of the parts are known.

147. **Equilibrium of solids supported by an axis.**—A solid is in equilibrium when its centre of gravity is supported. But this condition may be fulfilled in different ways, according to the method of support. If a disk of uniform density, fig. 94, is supported by an axis, passing through the centre *a*, which is also its centre of gravity, it will be in that sort of equilibrium which is called *indifferent*, because it has no tendency to revolve, either to the right or left, but remains at rest in all positions. If the axis passes through *b*, the disk will be in *stable* equilibrium; for if it is turned about its axis, the centre of gravity will move in the arc *m n*, and being no longer vertically below the axis, it will not be directly supported by it, but tends always to return to its former position. If the axis is at *c*, the equilibrium is *unstable;* for, if the centre of gravity is in the least removed from a position vertically above the axis, it cannot return, but it will describe a semi-circle in its descent, until it comes to rest exactly below the point of support.

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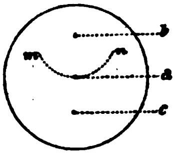

In general terms, therefore, a body attached to an axis may be in stable, unstable, or indifferent equilibrium, according as its centre of gravity is below, above, or within the axis.

148. **Equilibrium of solids placed upon a horizontal surface.**—In bodies placed upon a horizontal surface, the centre of gravity

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Give the illustration. 146. What is said of the centre of gravity of a ring? 147. When is a solid in equilibrium? When is it in indifferent equilibrium? When in stable and unstable equilibrium?

as in those which are suspended, tends to descend, and if the bodies are free to move, they will rest in one of the positions of equilibrium just named. If rays are drawn from the centre of gravity to every part of the surface, some of these rays will be oblique, and some perpendicular, or *normal* to the surface, whatever may be the external form of the body; and among the normal rays, there is generally a longest and a shortest ray. If the body rests upon the plane, at the extremity of one of the normal rays, its centre of gravity is evidently in the vertical line, drawn through the point of contact, and the body is in equilibrium. But if it rests at the extremity of an oblique ray, the centre of gravity is not supported, since it is not in the vertical of the point of contact, and the body falls.

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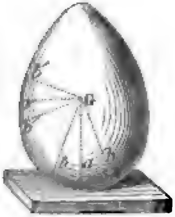

If the normal ray at the point of contact is neither longest nor shortest, but simply *equal* to the adjacent rays, the equilibrium is indifferent. Such is the case with a sphere, placed on a level plane; it rests in every position, for its centre of gravity cannot fall lower than it is. But this position cannot be assumed by a body not strictly spherical. For example, if an egg rests at the extremity of a longest ray, *a*, as in fig. 95, it will be in unstable equilibriun, since motion to either side tends to lower the centre of gravity, and enable it to fall; but if it rests at the extremity of a shortest ray, *a′*, it will be in stable equilibrium, since any motion sideways must *raise* the centre of gravity, and it will, therefore, fall back to its original position.

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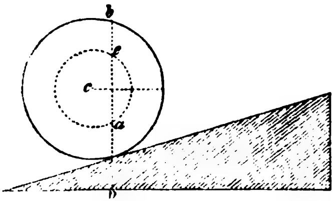

149. Centre of gravity in bodies of unequal density in different parts.—If the density of a body is unequal in different parts, its centre of gravity will be external to its centre of magnitude, and the body can come to rest in only two positions, when the centre of gravity is at the highest, and at the lowest place in the vertical of the point of contact. If a cylinder of this descrip-

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148. What is said of bodies placed upon a horizontal surface? Where is the centre of gravity when the body is placed at the extremity of one of the normal rays? What is the result when it rests at the extremity of an oblique ray?

tion were placed upon an inclined plane, as in fig. 96, it would be in equilibrium when its centre of gravity was at either *e* or *a*; if at *e*, and the cylinder were moved a little to the right, the centre of gravity would fall through the arc *e a*, but at the same time the cylinder itself would perform the apparent contradiction of ascending the plane.

150. **Equilibrium of bodies supported in more than one point.** When a body is supported by two points, the vertical, from its centre of gravity, ought to fall on the middle of the line which connects them. If a body has four points of support, the vertical should fall upon the intersection of their diagonals.

In carriages, if the vertical falls in a different manner, the load is improperly distributed, and the carriage will be liable to upset, in passing over an uneven road.

A body resting on a base more or less extended, will be in equilibrium only when the vertical from the centre of gravity falls within the area of the base; and the body will stand firmer in proportion as the centre of gravity lies lower, and the base is broader. A pyramid is, therefore, the most stable of all structures.

The singular feats exhibited by children's toys, and by rope-dancers, depend on the facility with which the centre of gravity is shifted, while it is always supported vertically above the base.

Laws of Falling Bodies.

151. **Gravity a source of motion.**—If a body at a distance from the earth's surface is not supported, it falls, and the force of gravity, which we have already seen to be the cause of weight or pressure, now manifests itself in producing motion. The body is said to fall; in reality, the motion is common to both the masses concerned, the earth and the descending body. They move towards each other in the inverse ratio of their masses; but since the mass of the earth is infinitely greater than the mass

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149. Where is the centre of gravity in a body whose density in different parts is unequal? Give the illustration. 150. Where should the centre of gravity fall in a body supported in two points? Where in a body supported by four points? What is said of carriages? What of a pyramid? What of rope-dancers? 151. How is gravity a source of motion?

of the falling body, the distance through which the earth moves is less in the same ratio, and it cannot be made evident to our senses.

Every one has observed the different velocities with which different bodies fall.

For example: a gold coin falls swiftly, and in a straight line, but a piece of paper descends in a winding course, and with a slow, hesitating motion. The popular explanation is, that the coin is heavy, and the paper light; but this is not the true reason, for when the gold is beaten out into thin leaves, its weight is the same, but the time of its fall is very much prolonged.

The variation is independent of gravity. Since the attraction of the earth acts equally, and independently on all the particles of matter of which a body is composed, it can be of no consequence, as far as this attraction is concerned, whether a body contains many particles or few; each particle is as strongly attracted alone, as when united into a mass with others. The differences in the time and manner of falling, are caused solely by the resistance of the air; which resistance varies, according to the shape and volume of the body, and not according to its mass, or the number of particles contained in it. This conclusion is established by the guinea and feather experiment. We take a glass tube, fig. 97, five or six feet long, closed at one end and mounted with a stop-cock at the other, and having placed a light and heavy body inside; a guinea and a feather, or a bullet and a piece of paper; we withdraw all the air from the tube, by means of an air-pump. Now let the tube be suddenly inverted, and the guinea and the feather will be seen to fall with equal rapidity, and strike the bottom together; but turn the stop-cock, and admit the air, and the one will descend swiftly, and the other will be retarded, just as it happens when they fall under ordinary circumstances. Thus when no resistance modifies the effects of gravity, it attracts all bodies with the same energy, and gives them the same velocity, whatever may be their weight, and whatever the kind of matter of which they are composed. The first law of falling bodies is,

1st.—*In a vacuum, all bodies fall with equal velocity.*

What is said of the mutual action of a falling body and the earth? Why do different bodies fall with different degrees of velocity? What is the guinea and feather experiment? What is the first law of falling bodies?

152. Velocity of falling bodies.—The fall of a body is a uniformly accelerated motion, because the earth's attraction acts at every moment in the same manner. The body gains a new impulse at each instant, and these impulses being equal, in equal times, the final velocity is equal to their sum, and proportional to the time of the fall. That is, the velocity of a falling body, at the end of the 2d second, is twice, and at the end of the 3d second, three times as great as at the end of the 1st second, &c. We have, therefore,

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2d.—*The final velocities of a body, falling freely, increase as the times of falling, or they follow the order of the natural numbers*, 1, 2, 3, &c.

153. Spaces described by falling bodies.—The velocity of a body when it begins to fall, is nothing; but from that moment it regularly increases. Let us represent the velocity acquired at the end of the 1st second by v; then the average velocity during the same time will be,

$$\frac{o+v}{2} = \frac{1}{2}v,$$

the arithmetical mean between o, the starting velocity, and v, the final velocity. A body moving at this rate, will traverse the same space in one second, which it would have fallen in one second; let this space $= g$; then the space being equal to the product of the velocity, and the time, $\frac{1}{2}v, \times 1$ sec. $= g$, or $v = 2g$; that is, the final velocity acquired by a body falling one second, is double the space through which it has fallen. It has been ascertained that in our latitude, this space is about $16\frac{1}{12}$ feet (16·0698 feet, see § 139); and $v = 32\frac{1}{6}$ feet.

In the 2d second, the body starts with a velocity of $v = 32\frac{1}{6}$ feet, and acquires, at the close, the velocity of $2v = 64\frac{1}{3}$ feet. The space fallen during the same time is $48\frac{1}{4}$ feet; viz: $32\frac{1}{6}$ feet by the velocity acquired during the 1st second, and $16\frac{1}{12}$ feet by the gradual action

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152. Why is the velocity of a falling body a uniformly accelerated motion? What is the second law of falling bodies? 153. What is said of the final velocities of a body falling freely?

of gravity, in this second only. Or as before, the space described by the body during the 2d second, is equal to the space it would have fallen with the mean velocity between its initial and final velocities; *i. e.* with the velocity

$$\frac{v+2v}{2} = \frac{3v}{2} = 3g;$$

the space, therefore, $= 3 \times 16\frac{1}{12} = 48\frac{1}{4}$ feet.

In the same way we find that the velocity acquired at the end of the 3d second, will be $3v = 96\frac{1}{2}$ feet; and in the same time the body will have fallen, with the mean velocity,

$$\frac{2v+3v}{2} = \frac{5v}{2}$$

through a space of $5g = 5 \times 16\frac{1}{12} = 80\frac{5}{12}$ feet.

A falling body, therefore, descends, in the 2d second of its fall, through three times, and in the 3d second, through five times the space fallen in the 1st second. We have, then,

3d.—*The spaces fallen through in equal successive times, increase as the odd numbers*, 1, 3, 5, 7, &c.

154. **Whole space described by a falling body.**—We have seen that the time of falling, and the final velocity, increase in the same ratio; and that the average velocity of any fall, is exactly half the final velocity; hence, any increase in the time of falling is attended by a corresponding increase of the average velocity during the whole fall. But the whole space described in any fall is jointly proportional to the time, and the average velocity; if, therefore, the time is doubled, the body falls not only twice as long, but also twice as fast, and it must descend through four times the distance. Again, if a body falls three times as long as another, it also falls with three times the average velocity, and descends, altogther, through nine times the distance. The times being represented by the order of the natural numbers, 1, 2, 3, &c., the spaces are represented by their squares, 1, 4, 9, 16, &c. A body in two seconds falls through four times, and in eight seconds, through nine times the space it descends in one second. Therefore,

4th.—*The whole spaces described by a falling body, increase as the squares of the times in falling.*

How may the velocities with which a body falls be estimated? What is the velocity in the 1st, 2d, and 3d seconds? What is the third law of falling bodies? 154. What is said of the whole space described by a falling body?

155. Result of the average velocity being double of the final velocity.—We have seen that a body falling for any time, acquires a final velocity which is double the average velocity of the fall; if, therefore, the action of gravity were suspended at the end of any given time, and the body continued to move with its acquired velocity, it would, in the same time, traverse twice the distance it had already fallen. For instance, the space fallen through in three seconds, is 144¾ feet, and the final velocity is 96½ feet; now a body falling uniformly, for three seconds, with this velocity, would pass through a space of 3 × 96½ = 289½ = 2× 144¾ feet.

5th.—*A body falling during any time, acquires a velocity which, in the same time, would carry it over twice the space of the first fall.*

156. Table expressing the laws of falling bodies.—The following table expresses the 2d, 3d, and 4th laws:—

Times, ...	1,	2,	3,	4,	5,	— t
The final velocities, . . .	2,	4,	6,	8,	10,	—2t
The space for each time, . .	1,	3,	5,	7,	9,	
The whole spaces, . . .	1,	4,	9,	16,	25,	—t^2

Let s = the space, t = the time, v = the final velocity, and g = the space fallen in the first second, then from the foregoing laws we may deduce the following equations, by which practical questions are readily solved.

$$(1)\ v = 2\,g\,t,\ \text{whence}\ (2)\ t = \frac{v}{2\,g}$$

$$(3)\ s = g\,t^2,\ \text{whence}\ (4)\ t = \sqrt{\frac{s}{g}}$$

By substituting in (3) the value of t (2)

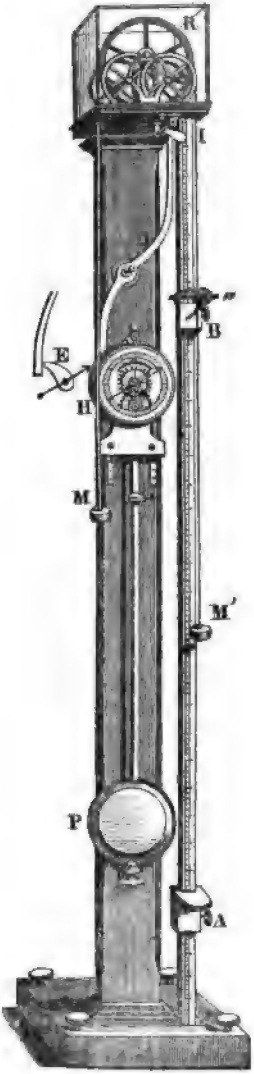
$$s = g \times \frac{v^2}{4\,g^2}, = \frac{v^2}{4\,g}$$

And substituting (4) in (1,)

$$v = g\sqrt{\frac{s}{g}} = \sqrt{4\,g\,s}$$

What is the fourth law of falling bodies? 155. What is the fifth law of falling bodies? Give an illustration. 156. What are the times of falling bodies? What the final velocities? What the space for each time? What the whole spaces? Explain the formulæ given.

98



157. **Verification of the laws of falling bodies.**—It is evident that the laws of falling bodies cannot be verified by direct experiment, because the results of such an inquiry would be disturbed by the resistance of the air, and the velocity of the fall is too great to be followed with the eye. But there are several indirect methods by which the intensity of the force of gravity may be diminished, without changing its nature. We can cause a falling body to descend so slowly, that the resistance of the air becomes imperceptible, and all the circumstances of the fall may be observed with entire precision. Galileo, who discovered and published these laws, about the year 1600, used an inclined plane in his experiments. The apparatus now generally employed, is called, from the name of its inventor, Atwood's machine. Fig. 98.

This apparatus is composed of a vertical column, about seven feet in height, surmounted by a friction pulley *R*, upon which is suspended a fine silk cord, carrying equal weights, *M* and *M'*, at its extremities. A scale of feet and inches is placed parallel to the path of one of the weights, to measure the spaces through which it falls, and the corresponding times are shown by the seconds pendulum *P*. To insure the simultaneousness of the fall with

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157. What is the verification of the laws of falling bodies? What did Galileo use in his experiments?

the beat of the pendulum, the weight is set in motion by the lever *D*, which is itself moved by an eccentric, (represented at *E*,) attached to the axis of the seconds hand.

The weights *M* and *M′* being equal, the force of gravity has no effect upon them, and they remain at rest in any position. But let one of them, as *M′*, be increased by a small additional weight *n*, and the equilibrium will be immediately disturbed. The gravity of *n* being the only disturbing force, the motion produced is of the same kind as the motion of a body falling freely, but the rate of acceleration, and the space fallen through, are each as much less as the mass of *n* is less than the combined masses of $n + 2M$.

For example: let *n* be a quarter of an ounce, and the weights *M* and *M′*, be each 24 ounces, or 96 quarter ounces. The whole mass to be moved, by the action of gravity upon *n* only, is 193 times the weight of *n*, and therefore the velocity imparted, and the space fallen through, must be 193 times less than the velocity and space of *n* falling freely.

Now let *M′* and *n* attached to it, be allowed to fall from *I*, the top of the scale, at the moment the click of the pendulum is heard. At the instant of the next beat, the weight will be seen to have fallen exactly 1 inch; during the second beat, through 3 inches more; during the third beat, through 5 inches; during the fourth beat, through 7 inches, &c., according to the 3d law of falling bodies.

In the same experiment it appears, that the whole space fallen through at the end of the 1st second, is one inch; at the end of the second second, 4 inches; at the end of the third second, 9 inches; at the end of the fourth second, 16 inches, &c., according to the 4th law.

To demonstrate the 2d and 5th laws, it is necessary to arrest the accelerated force at a given moment. This is accomplished by giving to *n* the form of a slender bar, long enough to be caught by the perforated slide *B*, while *M′* continues its course, with a uniform velocity, from the time it ceased to be acted on by the gravity of *n*. The velocity, at the end of any second, is determined by the space traversed during the next second. If the ring *B*, is fixed at the distance of one inch from the top of the scale, *n* will be detached at the end of the first second, and *M′* will descend uniformly through two inches, during each succeeding second. If the ring is fixed at the fourth division, the bar will strike at the end of two seconds, and *M′* will pass on at the rate of four inches per second.

Describe Atwood's machine. What is the result when the weights *M* and *M′* are increased? What distances will *M′* fall when a weight *n* is attached to it, in the 1st second? In the 2d? In the 3d? How are the 2d and 5th laws demonstrated?

158. **Application of the laws of falling bodies.**—The laws of falling bodies apply equally to every motion produced by a uniform force or pressure.

The descent of bodies upon inclined planes and curves, the rising of a cork through water, the alternate movement of the arms of a balance, &c., are motions produced by the constant attraction of the earth, and they all obey these laws.

In every such motion, the velocities are proportional to the times elapsed since the motion began; the final velocity is twice the average velocity; the spaces described in equal successive times, increase as the odd numbers; and the whole spaces increase as the squares of the times in which they are described. But in each instance, the velocity acquired, and the space described in a given time, will be different; and the rate of acceleration will never be so rapid as in the case of a body falling freely, because in no other instance will the force be so great in proportion to the quantity of matter moved.

A 5 lb. weight falls no faster than 1 lb., because, although there is 5 times as much matter to be moved, it also has 5 times as much force to move it.

159. **Descent of bodies on inclined planes.**—When a body is placed upon an inclined plane, it descends, as just explained, with a uniform motion, but its velocity is less than that of a body falling freely. The weight of the body, or its force of gravity, represented by the line $e\,g$, fig. 99, is resolved (§110,) into two parts, one of which is perpendicular to the plane, and produces pressure only, and the other, $e\,p$, (or $f\,g$,) is parallel to the plane, and is the cause of the accelerated motion. The triangles $e\,f\,g$, and $a\,b\,c$, being similar, their corresponding sides are proportional, and we have,

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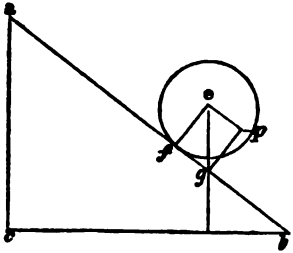

$$fg : eg :: ac : ab;$$

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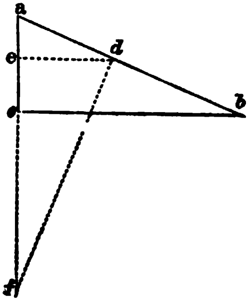
158. To what do the laws of falling bodies apply? Give examples. What is said of these motions? 159. What is said of the descent of a body on an inclined plane.

that is, the rate of acceleration on an inclined plane, is to that of a body falling freely, as the height of the plane is to its length. The final velocity depends solely on the height of the plane. In fig. 100, let *a c*, the height of the plane, be $\frac{1}{3}$ of its length *a b*; then, that part of the gravity of the body which produces motion, is $\frac{1}{3}$ of the whole force and the velocity acquired, and the space traversed in one second, by the action of this force, would be $\frac{1}{3}$ of the velocity and space of a body falling freely. Let the line *a f*, represent $16\frac{1}{12}$ feet, and take *a d*, equal to $\frac{1}{3}$ of *a f*; then, a body starting from *a*, would arrive at *d* in one second, or, falling freely, it would reach *f* in the same time.

100



Draw the horizontal line *e d*; the ratio of *a e* to *a d* is the same as the ratio of *a c* to *a b*; that is, *a c* is equal to $\frac{1}{3}$ of *a d*; and *a d* having been taken equal to $\frac{1}{3}$ of *a f*, *a e* is $\frac{1}{9}$ of *a f*. Since the spaces increase as the squares of the times, the body that would fall to *f* in one second, would fall to *e* in $\frac{1}{3}$ of a second; and (2d law) the velocity acquired at *e* would be $\frac{1}{3}$ of the velocity acquired at *f*. But we have already seen, that the velocity acquired by a body descending to *d*, is $\frac{1}{3}$ of the velocity acquired by the same body falling to *f*, in the same time; hence the velocity of a body descending the inclined plane to *d*, is equal to that of a body falling freely to *e*; and generally—

The velocity acquired at any given point on an inclined plane, is proportional to the vertical distance of that point below the point of departure.

From this it also follows that the average velocities are the same in descending all planes of the same height; and, therefore, the times of descent are proportional to their lengths.

160. **Descent of bodies in curves.**—If a body is made to descend a series of inclined planes, as in fig. 101, on arriving at any point of the series, its velocity will be the same as if it were falling freely from the level of the point of departure. The de-

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What does fig. 100 illustrate? Give the formulæ mentioned. What is the rate of acceleration on an inclined plane? Describe fig. 101. What is the velocity acquired at any given point on an inclined plane? What follows from this?

scent of bodies on curves, is governed by the same law; for we may consider a curve as composed of a great number of inclined planes, each one of which is so small as not to differ sensibly from the line of the curve.

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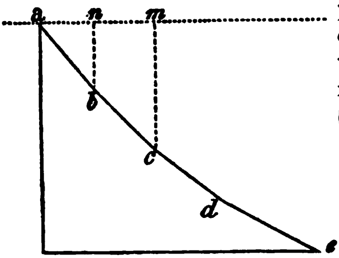

On arriving at the bottom of a plane or curve, a body will have acquired, (5th law,) a velocity, such as would carry it, in the same time, over a distance equal to twice the length of the descent, or cause it to ascend another similar curve. The ascent of the body being opposed by the constant force of gravity, will be retarded at a rate which exactly corresponds with its previous acceleration. On the double curve *A B C*, fig. 102, the body will have equal velocities at any two points at the same level; and the velocity being nothing when the body has arrived at *C*, it will descend again and mount to *A*, the point from which it first started. This alternate movement being caused by the constant force of gravity, would continue forever, and furnish an instance of perpetual motion, were it not for the resistance of the air and friction, by which the body is gradually brought to rest at *B*.

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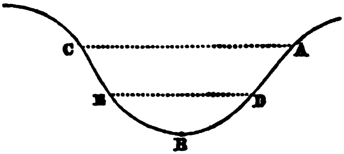

The pendulum is an example of a body alternately ascending and descending a very small circular curve.

The Pendulum.

161. **The pendulum.**—Any heavy body freely suspended at the extremity of a flexible wire, or thread, is called a pendulum. When at rest, the pendulum shows the exact vertical or direction of gravity, and it is then called a plumb-line. If moved from the

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160. What does fig. 102 illustrate? What velocity will a body acquire on arriving at the bottom of a curve? Describe fig. 103. By what is this alternate movement caused?

perpendicular into any other position, and then left free to fall, the pendulum swings in a vertical plane, rising on one side of the perpendicular to a height equal to that from which it had fallen on the other. The cause of this alternate movement is gravity. In the position *C M*, fig. 103, the pendulum is in equilibrium, because its weight is vertically beneath the point of suspension. But in the position *C m*, the weight is decomposed into two forces, of which one, *m B*, acting in the direction of the suspending thread, is destroyed by the resistance of the point of suspension; while the other, *m D*, solicits the pendulum to return to the vertical position at *M*. The pendulum does not rest at this point, although the accelerating force of gravity represented by *m D*, is then diminished to nothing, but the velocity acquired in descending the arc *m M*, is sufficient to carry it through an equal ascending arc *M n*. This movement is precisely similar to that of a ball rolling on a double curve, and if made once, it would be repeated forever by the action of the constant force of gravity, were it not for the resistance of the air and friction at the point of suspension.

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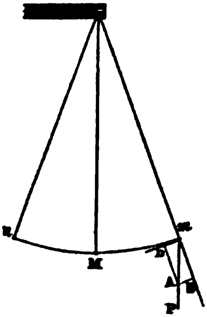

The angle *n C M*, or *M C m*, is called *the angle of elongation;* it is the deviation of the pendulum from the perpendicular.

The movement from *m* to *n*, or from *n* to *m*, is called *an oscillation or vibration;* from either of these points to the vertical line, or the reverse, is a half-oscillation or half-vibration.

The arc *n m*, divided into degrees, &c., measures the amplitude of each oscillation.

The time occupied by the pendulum in describing this arc, is the time or duration of an oscillation.

A distinction is made between the simple or mathematical pendulum, and the compound or physical one. The former consists of a single molecule of matter, suspended at the extremity of a line which is inextensible, and without weight. Such an

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161. What is a pendulum? What position does it take when at rest? What is the cause of the movements of a pendulum? Illustrate this by the figure. What is the angle of elongation? What is an oscillation? What is the time of oscillation? What is the mathematical pendulum? What is the physical pendulum?

instrument is purely ideal, and is conceived of only as a convenient means of investigating the laws of the real pendulum. The physical pendulum is constructed in a great variety of ways. That form of it which resembles the simple pendulum most nearly, and which is used in ordinary experiments, is composed of a small metallic ball, (lead or platinum is best,) suspended at the end of a very fine wire or thread.

162. **Laws of the oscillations of the pendulum.**—The movement of the pendulum is subject to the following laws:—

1st.—*Oscillations of small amplitude are made in equal times.*

2d.—*The time of oscillation is the same, whatever may be the weight or magnitude of the ball.*

3d.—*In pendulums of unequal lengths, the times of oscillation are proportional to the square roots of their lengths.*

163. **Demonstration of the laws of the oscillation of the pendulum.**—In verifying the first law, usually called the law of isochronism, the angle of elongation ($n\ C\ M$, fig. 103,) must not exceed 4° or 5°. Within this limit, the time of oscillation will be the same, whether the angle is 5°, or 3°, or 1°, or so small that the eye cannot distinguish it without the aid of a lens. The pendulum requires as much time to describe an arc of $\frac{1}{10}$ of a degree, as one of 10°. The reason of this remarkable fact is evident in fig. 103. That part of the force of gravity which produces motion, increases in the same ratio as the angle of elongation; and the greater length of the arc is exactly compensated by the greater velocity with which the pendulum describes it.

The 2d law is easily demonstrated by suspending balls of lead, iron, glass, ivory, &c., with threads of the same lengths, and causing them to oscillate. In any one experiment, the balls should be of the same form and diameter, in order that they may encounter an equal resistance of the air; in a vacuum such a precaution is unnecessary.

Newton, and more recently Bessel, greatly extended the limits of this experiment by using a pendulum having a hollow ball, which was filled, successively, with various substances; wool, feathers, liquids, &c.; that could not be otherwise submitted to trial. This experiment affords the most precise and unmistaka-

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162. What are the laws of the oscillation of the pendulum? 163. How is the 1st law demonstrated? How the 2d? How have the limits of this experiment been extended?

able proof that gravity acts on all bodies in the same manner. In the guinea and feather experiment, the proof of this principle is comparatively rude and imperfect. In that instance, the action of gravity can be seen only during the fraction of a second; but in the oscillations of the pendulum, it may be observed for successive hours, and with the greatest accuracy.

The demonstration of the 3d law is made by comparing pendulums of different lengths. If the lengths are in the ratio of 1, 4, 9, then the times of oscillation will be as 1, 2, 3, respectively. Let three such pendulums, arranged as in fig. 104, commence to oscillate at the same time; it will be found, that the one-foot pendulum makes two oscillations for each oscillation of the four-foot pendulum, and three oscillations for each one made by the nine-foot pendulum. The time of oscillation, and the length of the pendulum being known, we may determine by this law, 1st, the length of a pendulum which would oscillate in any proposed time; and 2dly, the time of oscillation of a pendulum of any proposed length. For the times of oscillation are as the square roots of the lengths, or, what is the same thing, the lengths are as the squares of the times. Hence,

$$L : l :: T^2 : t^2$$

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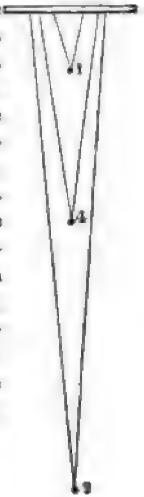

164. **Physical demonstration of the rotation of the earth by means of the pendulum.**—Foucault's famous pendulum experiment (1851) deserves attention, as it was the first physical demonstration that had been made, of the rotation of the earth upon its axis. The experiment consists in suspending a heavy ball to a long and flexible wire, and allowing the whole to vibrate freely, in the manner of a pendulum. Under these circumstances it will be found, that the plane of vibration gradually changes its position, turning slowly from east to west, or with the motion of the hands of a watch.

The connection between the motion of the pendulum plane

How is the demonstration of the 3d law made? Describe fig. 104. The time of oscillation and the length of pendulum being known, what may we determine by this law? 164. What is said of Foucault's experiment?

and the earth's rotation, may be easily understood. A pendulum set in motion, will continue in the same plane of vibration, however the point of suspension may be rotated. This may be proved by holding in the fingers a pendulum, made of a simple ball and string, and causing it to vibrate. Upon twirling the string between the fingers, the ball will rotate on its axis, without, however, affecting at all the direction of its vibrations. The reason for this is obvious; the swinging pendulum, when about to return, (after an outward oscillation,) from its point of rest, is made to move from that point by gravity alone, and can, therefore, fall in but one direction.

If a pendulum were oscillating at either of the poles of the earth, the plane of revolution, as it would not change with the revolution of the earth, would mark this revolution, by seeming to revolve in a contrary direction, and in 24 hours it would make apparently the whole circuit of 360 degrees. But, at the equator, the plane of vibration is carried forward by the revolution of the earth, and so undergoes no change with reference to the meridians. Between the equator and the poles, the time required for the pendulum to make 360°, varies according to the latitude, being greater the further from the poles.

The observed rate of motion of the plane of vibration, nearly coincides with that indicated by calculation. Thus, at New Haven, (N. lat. 41°, 18¼′,) the calculated motion, per hour, was 9·928°, the observed motion was 9·97°.

The greatest length of the pendulum wire hitherto employed, was that of 220 feet, in the Pantheon, at Paris. At Bunker Hill Monument, it was 210 feet long; at New Haven, 71 feet. The weight of the ball employed, (usually of lead,) has varied from 2 to 90 pounds. The longer the wire, and the heavier the ball of the pendulum, the greater will be the probability of accurate results, for when the mass of the body is great, and its motion slow, the resistance of the air will have but comparatively little effect on the direction of the vibration.

165. **Centre of oscillation.**—In the physical pendulum, the

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What does it consist of? What does the twisting string and ball illustrate? Why does not the swinging pendulum alter its direction when its point of support is rotated? What is said of a pendulum swinging at the poles? What of one at the equator? What is the observed rate of motion? In the experiments mentioned, what have been the length of pendulums and the weights of the masses suspended? What increases the probability of accurate results?

rod has weight as well as the ball; and all the material points of both rod and ball, are placed at different distances from the point of suspension. Let us examine the oscillations of any two of these material points, *m* and *n*, fig. 105. If they were suspended by separate threads, then, according to the 3d law, *m* would oscillate more rapidly than *n;* but if they are suspended by the same inflexible wire, they must move together, and make their oscillations in the same time. The first accelerates the second, and the second retards the first, so that their common velocity is intermediate between the velocity of either of them, oscillating alone. Such a compensation takes place in every oscillating body, and between the particles, which are nearer and those more remote from the point of suspension, there is always a point so situated, that it is neither accelerated nor retarded, but oscillates exactly as if it were suspended alone, at the end of a thread, without weight. This remarkable point is called the *centre of oscillation;* and its distance from the point of suspension is the *length* of the pendulum. This is equal to the length of a simple pendulum which would oscillate in the same time as the physical pendulum.

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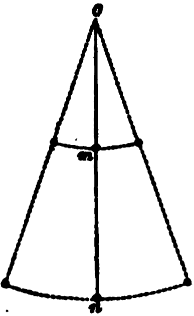

The position of the centre of oscillation depends upon the form, magnitude, and density of the several parts of the pendulum, and the position of its axis. If the rod of the pendulum is thick in proportion to the ball, its centre of oscillation will be higher than in a contrary arrangement. It is always below the centre of gravity, although whatever raises or lowers the centre of gravity, will change the centre of oscillation in the same direction. Whatever may be the positions of the point of suspension, and the centre of oscillation, they are always interchangeable; *i. e.*, if the pendulum is suspended by its centre of oscillation, these two points exchange their functions, and the oscillations are made in the same time as before. It is by an experiment of this kind, that the centre of oscillation, and consequently the length of a pendulum, is determined.

166. **Applications of the pendulum.**—The laws of the oscilla-

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165. What is said of the physical pendulum? Describe fig. 105. What point is called the centre of oscillation? What is its distance from the point of suspension? Upon what does its position depend? What is its relation to the centre of gravity?

tions of the pendulum already explained, would still be true, whether the force of gravity were greater or less, but the absolute time of an oscillation would not remain unchanged. If the intensity of gravity should be increased or diminished, the pendulum, like any other falling body, would move at a quicker or slower rate accordingly. Hence this instrument becomes the measure of the earth's attraction at different points on its surface; and because the intensity is inversely as the distance from the earth's centre, when the length of the radius at any place has been determined by measuring an arc of a meridian, the length of the radius at any other place may be found by counting the oscillations of a pendulum. The length of a pendulum which vibrates seconds at New York, *i. e.*, which makes one vibration in each second, is 39·10153 inches; if carried towards the equator, the same instrument would oscillate more slowly; if transported to a station north of New York, its oscillations would be made in a sensibly shorter time. Observations of this kind, therefore, furnish one method of determining the true figure of the earth.

167. **Measure of time.**—But the most important and universal use of the pendulum, is to measure time. This application depends upon its first law of motion; the law of isochronism. This property of the pendulum was the earliest physical discovery of the illustrious Galileo, made when he was a youth of seventeen, from having observed the swinging of a lamp in the cathedral of Pisa, while he was a choir boy. It was not, however, until 1657, that Huyghens, a Dutch philosopher, first attached the pendulum to a train of wheel-work, as seen in the ordinary clock.

Projectiles, and Central Motion.

168. **Projectiles.**—Whenever a body is thrown into the air, it is subject to the action of two forces; the projectile force which is momentary, and the constant force of gravity. The motion of a projectile is, therefore, a compound one, and its path will vary according to the relation of the two forces.

169. **Projection of a body vertically downwards.**—When a body is projected vertically downwards, its path is the same as

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166. What is said of the laws of the oscillations of the pendulum? What is the length of a pendulum vibrating seconds at New York? 167. What is the most universal use of the pendulum? Who discovered its first law of motion? What is said of Huyghens? 168. What is said of projectiles? 169. What is the path of a body projected vertically downward?

that of a body falling freely, but the space traversed is equal to the sum of the effects of the two forces.

170. **Projection of a body vertically upwards.**—If a body is thrown vertically upwards, its motion will be uniformly retarded. It is evident that the projectile force cannot interfere with the action of gravity, which diminishes the velocity of ascent, at the same rate as it accelerated the velocity of the descent in the last case. The laws of falling bodies apply here in the inverse order.

Thus, if a body is projected upwards with a velocity of 100 feet a second, in 3 seconds it would have risen by the projectile force alone, 3 × 100 = 300 feet; but in the same time it must have fallen, by the action of gravity, (4th law,) 9 × 16$\frac{1}{12}$ = 144¾ feet; hence, the place of the body at the end of three seconds, is 155¼ feet above the point from which it started.

As soon as the projectile force is expended, the body commences to descend, and passing every point on its downward path, at the same rate as in its upward flight, it acquires, at the end of its fall, a velocity equal to that with which it was projected.

171. **Projection of a body in any other direction than vertically upwards or downwards.**—If a body is projected in any other direction than vertically upwards or downwards, its path will be determined by the parallelogram of forces. Thus, if a cannon-ball is shot in the direction *a b*, (fig. 106,) with a velocity which would carry it through the space *a I* in one second, then it would continue in this line, passing through equal spaces in equal times. If it was acted upon by gravity alone, it would move in the vertical *a c*, through the spaces *I' II' III'*, in corresponding sections. But meanwhile, it is subject to the action of gravity, and, like any other body, must fall through the

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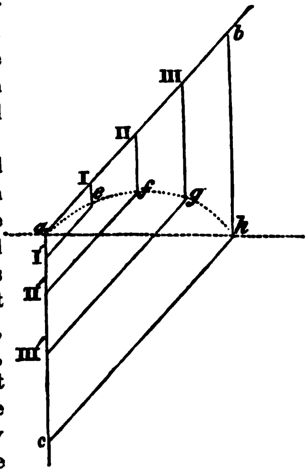

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170. What is said of a body projected vertically upwards? Give the illustration. What velocity does the body acquire at the end of the fall?

vertical space of $16\frac{1}{12}$ feet, during the 1st second; at the end of that time, therefore, it will be found at *e*, instead of at *I*. In the same manner, at the end of the 2d and 3d seconds, it will be at *f* and *g*, instead of *II* and *III*; and at the end of four seconds the body will arrive at *h*, the result being exactly the same as if it had been first carried by the projectile force in the line *a b* during four seconds, and then allowed to fall during four seconds by the action of gravity. Since the action of the projectile force is only momentary, while the effect of gravity is constantly increasing, the body will not describe the diagonals of the parallelograms, *a e*, *a f*, &c., but a curve, which in mathematics is called a parabola, indicated by the dotted line connecting *a e f g* and *h*.

By a similar construction, we find the path of a body projected horizontally, or obliquely downwards, in which cases the projectile will describe one-half of a parabola. In every case the path of the projectile is a complete or partial parabola, whose axis is in the direction of gravity; and its vertical distance below the line of projection at any given moment, is always equal to the space it would have fallen freely during the time since it was projected.

172. **When the direction of the projectile is inclined upwards**, we may resolve its initial velocity into two; a constant velocity in a horizontal direction, not affected by gravity, and another component, which causes the body to describe the ascending half of a parabola, until destroyed by the action of gravity, whereupon the descending half is described with the inverse velocity of the ascent. Therefore, the greatest height attained by the projectile, is equal to the space which it must fall, to acquire its initial vertical velocity, *i. e.*, the second component.

173. **Time of flight of a projectile.**—Hence, the time of flight of a projectile must be the very same as if the body had been shot vertically upwards, to the greatest height reached by it; *i. e.*, equal to twice the time of acquiring the initial vertical velocity by the action of gravity.

174. **Angle of elevation.**—The distance from the point of projection to the point where the body reaches again the same level, is called the horizontal range. With the same velocity of pro-

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171. If a body is projected in any other direction than vertically upwards or downwards how is its path determined? Give the illustration. Of what form is the path of a projectile? 172. What is said of a projectile when its direction is inclined upwards? 173. What is the time of flight of a projectile? 174. What is the horizontal range?

jection, the range is greatest when the angle of elevation is 45°; and for any elevation equally above or below 45°, as 40° or 50°, &c., the horizontal range will be equally diminished.

The effects of the resistance of the air will be mentioned hereafter.

175. **Central forces.**—The forces which unite in producing motion around a centre are of two kinds; the *centrifugal*, or centre-flying force, by which the body tends constantly to recede from the centre; and the *centripetal*, which is directly opposed to the first, and constantly attracts the body towards the centre.

A sling whirled rapidly around the hand, is a familiar illustration of central forces. The effort of the stone to fly off, or the centrifugal force, produces a constant tension of the string, which increases with the speed of revolution. The reaction of the hand, communicated through the string, confines the stone in a circular path, and may be regarded as a centripetal force. When the string is let go, the centrifugal force is not counteracted, and the stone flies off in a straight line, tangent to the circle, in consequence of the general principle of the inertia of matter.

When these two forces are everywhere equal to each other, the body will move with uniform velocity in a circle; but if they are differently related, the body will describe some other curve, with a variable velocity.

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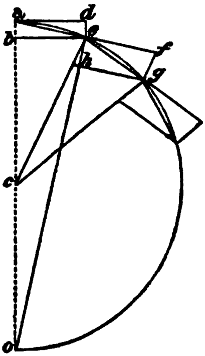

176. **Analysis of the motion produced by central forces.**—That the path of the body must be curvilinear, will be evident from the following analysis. Let a body placed at *a*, fig. 107, receive an impulse which would carry it, in one second, through the line *a d*, while at the same time it is attracted towards *c*, by a force sufficient to have drawn it in one second from *a* to *b*; then, according to the law of the parallelogram of forces, it will move through the diagonal *a e*. In consequence of its inertia, the body on arriving at *e*, will tend to continue its

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What the angle of elevation? 175. What are the two forces producing motion around a circle? Give an illustration of central forces. What will be the path described by a body when these forces acting upon it are equal? What when they are unequal? 176. Show by analysis that the path of the body must be curvilinear.

course in the straight line *e f;* but the centripetal force attracts it to *h*, and therefore it again describes a diagonal, *e g*. Now the attractive force at *c*, instead of acting at intervals, as we have supposed, is constant, and consequently the body will describe a curve; and since *e d*, which is the distance the body would have receded in one second, is equal to *a b*, the two forces are equal to each other, and the curve is a circle.

If we assume the arc *a*, *e*, to be very small, it will not sensibly differ from a straight line, and because the triangles *a e b* and *a e o*, are similar, we have,

$$ab : ae :: ae : ao$$

Hence

$$ab = \frac{ae^2}{ao}$$

That is, the centrifugal and centripetal forces of a body describing a circle with uniform velocity, are directly proportional to the square of the velocity, and inversely as the diameter, (or radius,) of the circle.

The relation of the forces may be expressed differently. The arc *a e* being the space described in one second, is the velocity of the body; but in curvilinear, just as in rectilinear movement, the velocity is equal to the space divided by the time, *i. e.*, equal to the circumference of the circle, divided by the time of revolution. Hence,

$$ae = \frac{2\pi r}{t} \, *$$

and substituting this value of *a e* in the previous equation, we have,

$$ab = \frac{2\pi r^2}{t^2};$$

That is to say, if two bodies move in different circles, and in different times, their centripetal and centrifugal forces will be as the radii of the circles, and inversely as the squares of the times of revolution.

It is evident, also, that the centrifugal force is proportional to the mass of the body.

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* The ratio of the circumference of a circle to its diameter, is 3·14159, and this number is usually represented by the Greek letter π.

To what are the central forces of a body proportional? How may they also be expressed?

177. **Illustration of the effects of centrifugal force.**—The effects of centrifugal force may be illustrated by the apparatus represented in fig. 108. The frame *A B* is screwed on an axis which may be rapidly rotated by turning the wheel *P*. Two perforated balls are placed at the centre of the wire, and the machine being put in motion, they will be projected from the centre, and strike the frame at the same instant, if they have the same mass. If they are placed equally but have unequal masses, the greatest will strike first; if having equal masses they are placed unequally, the one furthest from the centre will move first. The experiment is varied by substituting a frame, fig. 109, with glass tubes, containing liquids of unequal densities, as mercury and water; during the rotation, the denser liquid will rise first to the top of the tube.

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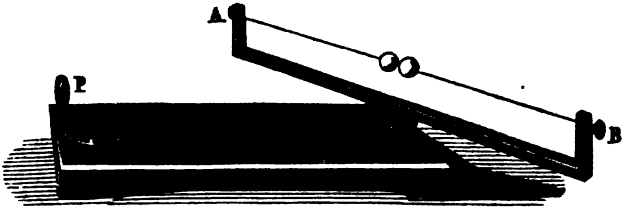

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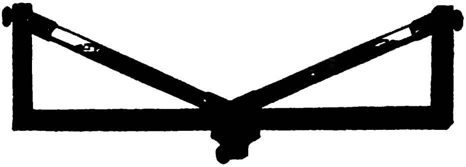

178. **Revolution about an axis.**—If a solid body revolves about a fixed axis, all parts of its mass must revolve in the same time; but the velocities of the different parts, and consequently their centrifugal forces, will be proportional to the perpendicular distance of each from the common axis. The parts which are furthest from the axis, will have the greatest velocity, and tend most to fly off from it. If the revolving body is spherical, like the earth, the centrifugal force will be greatest at the equator,

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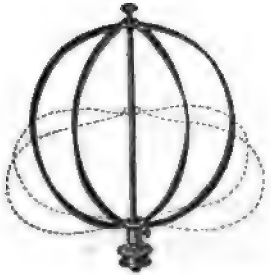
177. Give an illustration of the effects of centrifugal force. Mention another illustration.

and diminish regularly from thence to the poles, where it becomes nothing. The centrifugal force is opposed to gravity, and lessens its intensity; but the direction of gravity being always perpendicular to the earth's surface, while the centrifugal force acts at right angles to the axis, they are not directly opposed to each other except at the equator. There, gravity is diminished by the whole effect of the centrifugal force, (equal to $\frac{1}{289}$th part of gravity,) but at every other point, the centrifugal force is resolved into two parts; of which one is perpendicular to the surface, and lessens the effect of gravity, and the other is tangent to the surface, and urges the mass to accumulate at the equator. Such an accumulation took place in the originally plastic or fluid condition of the earth, so that the equatorial diameter is greater than the polar by about 26 miles.

179. **Effect of a centrifugal force on a yielding mass.**—This effect of centrifugal force upon a yielding mass, may be shown by the apparatus, fig. 110. Two circles of wire or flexible metallic ribbons, are attached below to an axis, and above to a sliding ring, and being rapidly rotated by the whirling table, the circles flatten in the direction of the axis, and bulge at the equator, as shown by the dotted lines.

110



If the velocity of the earth's revolution on its axis were increased 17 times, the centrifugal force would be 289 (17^2) times greater, or equal to gravity. In this case a body would have no sensible weight; and if the velocity were still further increased, the ocean would be flirted off in spray as water from a grindstone in rapid revolution.

If the figure of the revolving solid is symmetrical, and its mass of uniform density, and equally arranged about its axis, the centrifugal forces of its particles will mutually balance each other, and produce no pressure on the axis. This is called a free axis, and such is the axis of the earth.

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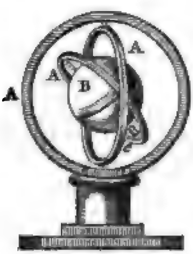
178. What is said of the revolution of a body about a fixed axis? What of the centrifugal force when the body is spherical? What is the relation of this force to gravity? What at other points than the equator? 179. Give an illustration of the effect of centrifugal force on a yielding mass.

180. **Bohnenberger's machine.**—It is in consequence of the operation of the law of inertia, (§ 27, 28,) that moving bodies preserve their planes of motion. This is true as well of planes of rotation as of planes in a rectilinear direction. By means of Bohnenberger's machine, we may illustrate the tendency of rotating bodies to preserve their plane of rotation, and the invariability of the axis of the earth during its revolution. Bohnenberger's machine consists of three movable rings, *A A A*, fig. 111, placed one within the other, and connected by pins at right angles to each other, in the same way as the gimbals that support a compass. In the smallest ring there is a heavy metallic ball supported on an axis, which also carries a little roller *c*. The ball is set in rapid rotation by winding a small cord around *c*, and suddenly pulling it off. The axis of the ball will continue in the same direction, no matter how the position of the rings may be altered; and the ring which supports it will resist a considerable pressure tending to displace it.

111



181. **The gyroscope, or rotascope,** is an instrument by which

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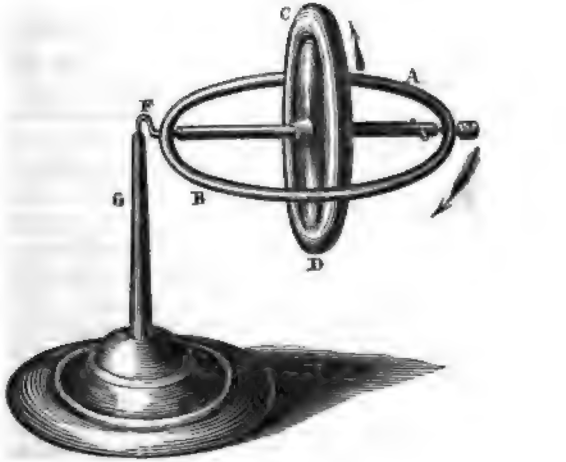

What would be the result if the velocity of the earth's revolution on its axis was increased 17 times? What is called a free axis?

we may illustrate the result of centrifugal force as modified by inertia and gravity; and also show, as in Bohnenberger's machine, the tendency of rotating bodies to preserve their plane of rotation. A common form of the rotascope, fig. 112, consists of a metal ring, *A B*, inside of which is placed a metallic disc, *C D*, loaded at its edge, and which turns, independently of the ring, upon the axis. Motion is communicated by means of a cord, wound around the axis of the disc and suddenly drawn off. If, when the disc is rotating rapidly, it be placed on the steel pin supported on the column *F*, it seems indifferent to gravity, and instead of dropping, it begins to revolve about the vertical axis. The motion of the axis is similar to the *precession of the equinoxes.* The motion of revolution is opposite in direction to the rotation of the disc, and when one of these motions is the greatest, the other is the least.

When the rotating disc is placed in a vertical plane and made to rotate, each particle has a horizontal and vertical component. (§ 119.) As soon as the disc, from its weight, begins to incline from its original vertical position, the horizontal components still remain parallel to the new position, but the vertical components do not. If the upright edge of the disc nearest the eye is ascending, this edge is pushed to the left, and the opposite edge to the right. These two forces, resulting out of the deviation of the original vertical components from parallelism with the disc, act as through a bent lever, to turn the whole disc around a vertical axis, in a direction opposite to its rotation. This can be shown, experimentally, by pressing with the fingers upon these two parts of the edge. As soon as the motion round the vertical axis begins, the horizontal components of the original rotation no longer retain their parallelism with the disc. But the tendency to preserve this parallelism, in other words, the tendency of the disc to preserve unchanged its plane of rotation, generates force which acts on the top of the wheel, to the left, and at the bottom of the wheel, to the right. These forces acting by leverage, tend to lift the wheel, as may be seen by pressing in the same way with the fingers. When friction is excluded, this uplifting force is an exact balance of gravity, and the wheel neither rises or falls. (*Toggen. Annal.*)

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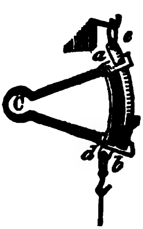
180. What may we illustrate by Bohnenberger's machine? Describe it. 181. What is said of the Gyroscope? Describe the common form of this instrument. In what direction is the motion of revolution? Give the explanation of its movements. When the wheel is revolving why can we not move it sideways?

If, when the wheel is rotating rapidly, it is held in the hands with the axis horizontal, it may be moved upwards or downwards, forwards or backwards, without difficulty; but if an attempt is made to move it sideways, we are opposed by a force, (inertia,) which is greater as the velocity of the wheel is greater.

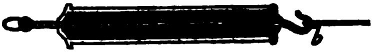
182. **Dynamometers.**—Instruments for measuring force, and especially the relative strength of men and other animals, are called dynamometers. One of the most simple of these is represented in fig. 118; it consists of a steel spring *a C b*. The metallic arc *a d* is fixed near the end of the limb *C a*, and passes freely through an opening in the other limb. The graduated arc *b e*, is fixed, in like manner, in the limb *C b*. The amount of the force exerted at the points *e* and *d*, determines the degree to which the two limbs will approach, and is represented in pounds on the graduated arc.

118



183. **Le Roy's dynamometer.**—Fig. 114 consists of a steel spring, coiled within a cylindrical tube. The end *n* of the spring is attached to a rod of metal, graduated in pounds and ounces, which is drawn out more, as the force *b* applied is greater.

114



184. **Reynier's dynamometer**, fig. 115, consists of a steel spring, *m a n b*, of which the part *a* and *b* approach each other, when a force is exerted at the points *m* and *n*. An arc graduated in lbs. is attached to the spring at the point *a*, and carries a needle, *r o*, worked by a lever, *c*. The position of this needle upon the arc, indicates the amount of the force exerted. If it is wished to determine the strength or force exerted by any animal or machine, as the strength exerted by a horse in drawing a plow through the ground, it is only necessary to attach one end of the instrument, as *n*, to

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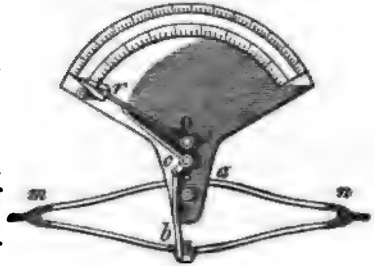

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182. What is a dynamometer? Describe fig. 118. 183. What is Le Roy's dynamometer? 184. Describe Reynier's dynamometer.

the plow, and have the horse attached to the other end, *m*. The degree which is marked by the pointer when the horse moves, represents in lbs. the force exerted.

Another dynamometer is often used, similar in construction to the last, only that the force is exerted at the points *a* and *b*, fig. 115, which are made to approach by a contrivance similar to that shown in fig. 113. It is evident, that in this last arrangement, the force is applied in the most favorable position for producing the maximum effect in collapsing the spring; while in Reynier's dynamometer, the force is applied where only the minimum effect is produced, and the instrument is therefore generally employed for determining only very considerable forces.

185. **Animal strength.**—The mechanical effect produced by men and animals, is subject to extreme variation, according to the various circumstances under which it is applied. The effect produced is determined by multiplying the load (or weight) by the speed. There is always a certain relation between the elements, which will give the maximum effect; for the load may be so great, that it will require all the strength of the animal to support it, and then he cannot move; or again, the animal may have a speed of motion so great, that he cannot carry any load, however small.

186. **Strength of men.**—It has been found, that the strength of a man may be exerted for a short time, most advantageously, in raising a weight, when it is placed between his legs. The greatest weight that can be raised in this manner, varies from 450 to 600 lbs; its average amount does not, however, exceed 250 lbs.

The greatest mechanical effect from muscular force is obtained, when the animal acts simply by raising his weight to a given height, and then is lowered by simple gravity, as upon a moving platform, the animal actually resting during the descent. In other words, the animal affords a convenient mode of raising a given weight, (his own,) to a certain height. Thus, if two baskets are arranged at each end of a rope hung over a pulley, and a weight to be raised is placed in one of the baskets, one or more men, whose weight is greater than that of the load to be raised,

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What is said of another dynamometer similar in form to Reynier's? 185. What is said of the muscular strength of a man and a horse? 186. How may the strength of a man be exerted most advantageously in raising a weight? What is the greatest weight that can be raised in this manner? What is the average weight? How is the greatest mechanical effect produced by an animal?

can, by getting into the empty basket, raise the weight as often as may be required. It has been found by experiment, that in this way, a man working eight hours, can produce an effect equivalent to 2,000,000 lbs. raised one foot; while at a windlass, an effect of only 1,250,000 lbs. is produced, and at a pile engine, only 750,000 lbs. In the tread-mill, the daily effect of men of the average strength, is 1,875,000 lbs. raised one foot. Spade labor is one of the most disadvantageous forms in which human labor can be applied; the force exerted being always much greater than the weight of the earth raised. The muscular effect of the two hands of a man, is about (50 *k*) 1,112 lbs., and for a female, about two-thirds of this quantity.

187. **Horse power machines.**—One of the most advantageous methods of applying the strength of animals, is by machines constructed upon the principle of the tread-mill. In practice, however, it has been found more convenient to apply horse-power to machinery by means of a large beveled or toothed wheel, fixed horizontally on a strong vertical axis. The horses are attached to projecting arms of this wheel, and as they move in their circular path, they push against their collars, and make the wheel revolve. This beveled wheel acts on a beveled pinion attached to a horizontal shaft, in connection with the machinery to be set in motion. The maximum effect which a horse can exert in drawing, is 900 lbs., but when he works continuously, it is much less. In the machine just mentioned, a horse of average strength produces as much effect as seven men of average strength working at a windlass. According to experiments made in Scotland, it appears that the average load which a single horse can draw, at the rate of 22 miles per day, in a cart weighing 7 cwt., is one ton, of 2240 lbs.

188. **Table of the comparative strength of men and other animals.**—The following estimates of the relative strength of man and other animals, have been given by the authorities whose

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Give the example mentioned. What is the effect a man can exert in this way equivalent to? What is said of the tread-mill, and spade labor? What of the effect of the two hands of a man? 187. What is said of horse power? How is it most advantageously employed? What is the maximum effect a horse can exert in drawing? What is the comparative strength of horses and men? What is said of the load a horse can draw?

names are indicated, Coulomb's estimate of the labor of a man being in each case taken as the unit.

Carrying loads on the back, on a level road.

Horse, according to Brunacci,	4·8
" " " Wessemann,	6·1
Mule, " " Brunacci,	7·6

In drawing loads on a level road, with a wheeled vehicle.

Man with wheelbarrow, according to Coulomb,	10·0
Horses in four-wheeled wagon, " "	175·0
" in two-wheeled cart, according to Brunacci,	243·0
Mule " " " " " " "	233·0
Ox " " " " " " "	122·0

Hassenfratz gives the following comparative estimate.

In carrying loads on a level road.		In drawing loads on a level road.	
Man,	1·0	Man,	1·0
Horse,	8·0	Horse,	7·0
Mule,	8·0	Mule,	7·0
Ass,	4·0	Ass,	2·0
Camel,	31·0	Ox,	4 to 7·0
Dromedary,	25·0	Dog,	0·6
Elephant,	147·0	Reindeer,	0·2
Dog,	1·0		
Reindeer,	3·0		

189. **Steam power.**—Water is converted into steam by the application of heat. Steam is an elastic condensible vapor, capable of exerting great force. During the conversion of a cubic inch of water into steam, a mechanical force is exerted, which may be stated, in round numbers, as equivalent to a ton weight raised one foot high. The water is merely the medium by which the mechanical effects of heat are evolved. The real moving power is the combustible, the coal or wood consumed in the evaporation of the water.

The maximum effects from a given weight of coal, in evaporating water, and consequent mechanical effect, have been ob-

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188. Give the relative weights which different animals can carry on their backs. The relative weights they can draw in wheled vehicles. Mention some of Hassenfratz's estimates of the comparative weights different animals can carry and draw. 189. What is said of the conversion of water into steam? What is the real moving power? What are the maximum effects obtained by coal in evaporating water?

tained in Cornwall, England, where a bushel of coal, weighing 84 lbs., has produced a mechanical effect equivalent to 120,000,000 lbs. raised one foot. Probably 100,000,000 is the maximum mechanical effect attainable, in regular work, by the consumption of a bushel of coal.

As the maximum effect produced by man is 2,000,000, and that of a horse, 10,000,000, it follows, that one bushel of coal consumed daily, may perform the work of 50 men, or ten horses.

In the chapter on heat and the steam-engine, this subject will be more fully considered. It is introduced here only for the sake of the convenient standards of force it gives us.

Theory of Machinery.

190. **Principle of virtual velocities.**—It was shown in § 111, that when a body, having a fixed point of support, is acted on by two parallel forces in the same direction, the forces will be in equilibrium, if they are to each other inversely as their distances from the supporting point. Thus in fig. 116, if an inflexible rod, supported at C, is acted on by two forces, W and P, such that,

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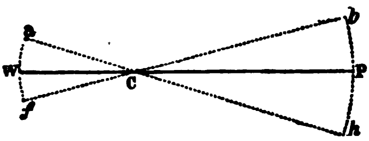

$$W : P :: C P : C W$$

then they will be in equilibrium. But in every proportion, the product of the first and last terms is equal to the product of the second and third; and instead of saying that the forces are inversely as their distances, the same thing is expressed by

$$W \times C W = P \times C P$$

The principle may be illustrated in another manner. Let the bar be made to oscillate gently about the point of support, or axis. It is plain that the spaces described by the ends of the bar will be proportional to their distances from the axis; for the angles at the axis being equal, the arcs $a f$ and $b h$ are directly

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What is said of the mechanical effect produced by the combustion of a bushel of coal, as compared with men and horses? 190. What is said of the principle of virtual velocities? How may it be illustrated? Give another illustration.

proportional to their radii, or distances from the axis, $C\,W$ and $C\,P$. Hence,

$$W : P : b\,h : a\,f,$$

That is, two forces are in equilibrium when they are to each other inversely as the spaces which they describe. The arcs being described in the same time, represent the velocities, and the principle is usually thus stated: *forces in equilibrium must be to each other inversely as their velocities.* The products, therefore, of the forces multiplied by their respective velocities, are equal.

$$W \times a\,f = P \times b\,h$$

These products are called the moments of the forces, (§ 126,) and forces are always in equilibrium when their moments are the same. If the movement is doubled or halved, or varied in any proportion, the efficacy of the force is doubled or halved, or varied in the same proportion. Any two forces will balance each other if they conform to the conditions just explained.

A force of 1 lb. will balance one of 1000 lbs., if they are applied so that the motion of the first, through 1000 inches, is attended by a motion of the other through 1 inch, and *vice versa.*

Any means by which two forces are brought into this relation with each other, constitutes a machine.

191. **Machine, power, weight.**—A machine, then, is an instrument or apparatus by which force may be transmitted from one point to another, usually with some modification of its intensity or direction.

In the language of mechanical philosophy, the force applied to a machine is called *the power;* the place where it is applied, *the point of application;* and the line in which this point tends to move, is *the direction of the power.*

The resistance to be overcome, is called *the weight;* and the part of the machine immediately applied to the resistance, is *the working point.* The moving powers, and the resistances, are both extremely various; but of whatever kind they may be, they

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When are two forces in equilibrium? What is the result when the moment is doubled? Give an illustration of the equilibrium of forces? 191. What is a machine? What is the power? What the weight? What the working point?

can always be expressed by equivalent weights, *i. e.*, such as being applied to the machine, would produce the same effects.

192. **Equilibrium of machines.**—When the power and weight are equal, the machine is in equilibrium, and it may be at rest, or, as is usually the case, in a state of uniform motion. If a machine in this case is put into uniform motion, it must continue to move indefinitely; for the power and weight being equal, neither of these forces can stop or modify the motion, without some additional force, which is contrary to the supposition.

Thus, if an engine draws a railway train with uniform velocity, the power of the engine is in equilibrium with the resistance of the train. At starting, the power is greater than the resistance, and the motion of the train is, consequently, accelerated, until the resistance becomes equal to the power, when equilibrium is again established. If any part of the power is now withdrawn, the power becomes less than the resistance, and the motion is consequently retarded until the train is brought to rest.

The mechanical energy, moving force or moment of the power, is found by multiplying its equivalent weight by the space through which it moves, or its velocity; and the moment of the resistance is estimated in the same manner. As we have just seen, the relation between these movements determines the state of the machine.

193. **Utility of machines.**—It is sometimes said, in illustration of the usefulness of machines, that a great weight may be supported or raised by an insignificant power; but such statements, if literally understood, are obviously untrue. No machine, however ingenious its construction, can create any force, and therefore the working point can exert no more force than is transmitted to it from the source of power. Every machine has certain fixed points, which are arranged to support any required part of the weight, while the remainder of the weight, and that part only, is directly sustained by the power. This remainder cannot be greater than the power.

194. **Relation of power to weight.**—But if the weight is not merely supported, but raised through a given space, then the power must move through a space as much greater than the

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192. When is a machine in equilibrium? Give an example. How is the mechanical energy found? 193. What is said of the utility of machines?

weight moves through, as the weight itself is greater than the power; in other words, the power and weight must be inversely as their velocities. This inverse proportion is expressed when it is said, that power is always gained at the expense of time.

To raise 1000 lbs. to a height of one foot by a single effort, would require a force equivalent to 1000 lbs.; but the same thing may be accomplished by a power of 1 lb. acting for 1000 times successively, through a space of one foot. If a man by exerting his entire strength could lift 200 lbs. to a certain height, in one minute, no machine whatever can enable him to lift 2000 lbs. to the same height in the same time. He may divide the weight into ten parts, and lift each part separately; or by the intervention of a machine he may raise the whole mass together, requiring, however, ten minutes for the task.

On the other hand, it is often the object of a machine to move a small resistance by a great power.

In a watch, the moving force of the mainspring is very much greater than the resistance of the hands, revolving about the dial. In a locomotive engine, each motion of the piston backwards and forwards, moves the train through a space equal to the circumference of the driving wheel; if the length of stroke is one foot, and the circumference of the wheel 12 feet, then the velocity of the piston will be to the velocity of the train, as 2 to 12; consequently the power acting on the piston, is greater than the resistance of the train, in the proportion of 12 to 2.

195. **Adaptation of the power to the weight in machinery.**— The use of machines is to adapt the power to the weight. If the intensity, direction, and velocity of the power, were the same as the intensity and direction of the resistance, and the velocity required to be given to it, then the power might be directly applied to the resistance, without the intervention of a machine. But if a small power is required to move a great resistance; or, if a power acting in one direction, is required to impart motion in another; or, to impart a velocity greater or less than its own, then it is necessary to employ a machine which will modify the effect of the power in the required manner.

196. **Motion of the power employed changed by machines.**—

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194. What is said of the relation of power to weight? Give illustrations. What is said of a watch? A locomotive? 195. What is said of the adaptation of the power to the weight in machines?

Besides these, the motion of the power may differ from the motion required in the resistance, in a great variety of ways.

The power may have a reciprocating motion, as in the locomotive engine, and be required to produce a continuous motion in a straight line, as in moving a train upon a railway. Or, the power may have a rectilinear motion, as a stream, and be employed to produce the circular motion of the stones in a grist-mill, or the reciprocating motion of a saw, in a saw-mill.

In every class of machines, the relations existing between the power and the resistance, depend solely on the construction of the machine; but even a general account of the ingenious contrivances by which the moving force is regulated, modified, and adapted to the varying conditions and requirements of the resistance, would lead us far beyond the limits and design of this work.

The Simple Machines.

197. **Classification of machines.**—Machines which consist of only one part, are called simple machines; compound machines are made up of various combinations of the simple machines.

These elementary machines, or mechanical powers, are comprised under three classes:

I. The lever.
II. The pulley.
III. The inclined plane.

The wheel and axle is a modification of the lever; and the wedge and the screw are essentially the same as the inclined plane.

Notwithstanding the endless variety and complexity of machines, their individual parts may always be reduced to one of these classes. Every machine, however complex, is constructed according to the fundamental law, already explained, that the power and weight must be to each other inversely as their velocities.

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196. What is said of the motion of the power employed changed by machines? Give illustrations. 197. What are simple machines? What are compound machines? What are the three classes of mechanical powers? What is the wheel and axle a modification of? What the wedge and screw? What fundamental law is every machine constructed according to?

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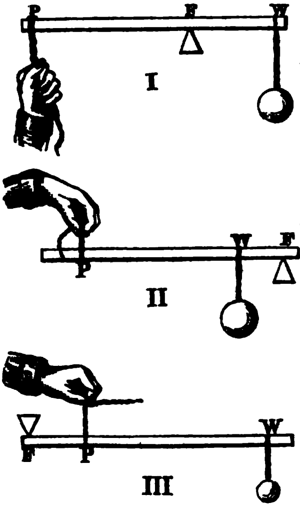

198. **The lever.**—The lever is an inflexible rod, turning about a fixed point of support, or axis, which is called the fulcrum. The parts of the lever extending on each side of the fulcrum, are called the arms of the lever. Levers may be straight or bent, simple or compound. It is usual to divide levers into three classes, according to the position of the fulcrum, in relation to the power and weight. They are represented in fig. 117. In the first class, the fulcrum is between the power and weight. In the second, the weight is between the fulcrum and power. In the third, the power is between the fulcrum and weight.

Whatever may be the class of the lever, the power and weight will be in equilibrium when they are inversely as their distances from the fulcrum. In each of the levers in the figure, we shall have,

$$P : W :: FW : FP$$

Or

$$P \times FP = W \times FW$$

Consequently, the moment of the power, or its tendency to turn the lever, would be augmented either by increasing the power itself, or its distance from the fulcrum. The same is true of the weight. The distance of a force from the fulcrum, is called its leverage.

199. **Equilibrium when the forces act obliquely to the lever.** In the preceding examples, the direction of the forces is perpendicular to the lever; but they may act obliquely, the only condition necessary to equilibrium being, that their moments about the fulcrum must be equal, and their directions opposite. But the effective distance of a force from the fulcrum, is always the

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198. What is a lever? Mention the position of the power, weight and fulcrum in the three classes. When are the power and weight in equilibrium?

perpendicular distance from that point to the line of direction of the force. Thus, in fig. 118, if the power acts in the direction *B P*, the moment of the power is not expressed by $P \times AF$, but by $P \times BF$. Hence, if the arms of the lever are bent or curved, their effective length is found by drawing perpendiculars from the fulcrum, upon the directions of the power and weight.

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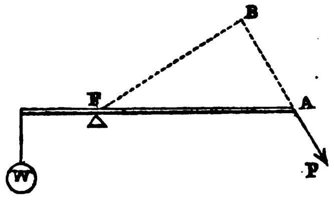

200. Compound levers.—When a given power is required to sustain a considerable weight, and it is not convenient to use a very long lever, a composition of levers, or compound lever is employed. When such a system is in equilibrium, the power, multiplied by the continued product of the alternate arms of the levers, commencing from the power, is equal to the weight multiplied by the continued product of the alternate arms, commencing from the weight. For example, the system represented in fig. 119, consisting of three levers of the first class, will be in equilibrium when,

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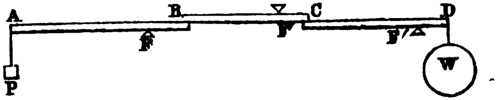

$$P \times AF \quad BF' \quad CF'' = W \quad DF'' \quad .CF' \quad BF.$$

If the long arms are 6, 4, and 5 feet, and each of the short arms 1 foot, then 1 lb. at *A* will sustain 120 lbs. at *D*; but if a simple lever had been used, the long arm being increased simply by adding these quantities, we should have gained a power of only $6 + 4 + 5 = 15$ to 1.

The pressure on the fulcrum, when the power and weight are in equilibrium, is found by applying the principle of the composition of forces, (§ 109.) In a lever of the first class, the resultant

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199. What is said of equilibrium when the force acts obliquely to the lever? Mention example of a bent lever. 200. What is said of compound levers? When is a compound lever in equilibrium? Give the formulæ? How is the pressure found when the power and weight are in equilibrium? What is the resultant in the levers of the three classes?

of the power and weight is a single force, equal to their sum, and passing through the fulcrum; consequently, the pressure will be equal to the sum of the power and weight. In a lever of the second or third class, the resultant is equal to the difference of the power and the weight.

201. **Applications of the lever.**—Levers of the first class are illustrated by familiar examples.

A crowbar used in raising stones, and a poker used to raise the coals in a grate, are levers of this class. Scissors, snuffers, and pincers, are pairs of levers of this class, the joint which connects them being their common fulcrum. The common hammer is a bent lever of the first class, the claw being the arm applied to the resistance, and the handle, the arm acted on by the power.

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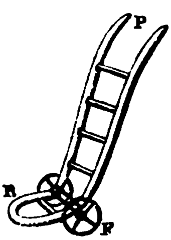
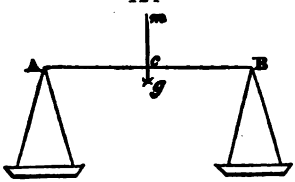


An example of the bent lever is seen in the ordinary truck, fig. 120, used for moving heavy goods a short distance. In this machine, the axis of the wheels *F* is the fulcrum, against which the foot is placed, while the weight at *R* is raised off the ground by the hand, applied at *P*.

One of the most useful applications of the lever is seen in the balance. It consists, essentially, of a lever of the first class, suspended at its centre, and therefore having equal arms. The scales are sustained by cords hung from the extremities of the beam, *A B*, fig. 121, called points of suspension, and these points must be in a line, at right angles to the line joining the centre of motion, and the centre of gravity. The centre of gravity, *g*, is below the fulcrum, for if it should coincide with the fulcrum, the balance would rest in any position, indifferently; but if it were above the fulcrum, the beam would be upset by the least disturbance. In a perfect balance, all the parts on each side of the centre of gravity must be absolutely equal. In practice, such accuracy is impossible, but the exact weight of a body may be found by the process of double weighing, devised by Borda.

121



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201. Give examples of levers of the first class. Give an example of a bent lever? What is said of the balance? What is said of a perfect balance? How may the exact weight of a body be found?

Let the body to be weighed be accurately counterpoised by means of shot or sand. This being done, remove the body and substitute for it known weights, until equilibrium is again restored. The amount of this weight will exactly express the weight of the body, since being placed under exactly the same circumstances as the body, it produced the same effects. If a balance has been falsified for dishonest purposes, the cheat can be detected by shifting the weights, which produce equilibrium. To find the true weight by means of such a balance, weigh the substance, first in one scale, and then in the other; multiply the two weights together, and take the square root of the product.

The steelyard is a lever of the first class, with unequal arms. The body *P* to be weighed, is attached to the short arm, *A*, fig. 122, and counterpoised by a constant weight, *Q*, shifted upon the longer arm marked with notches to indicate pounds and ounces, until equilibrium is obtained. It is evident that a pound weight at *D*, will balance as many pounds weight at *P*, as the distance *D C* is greater than *A C*.

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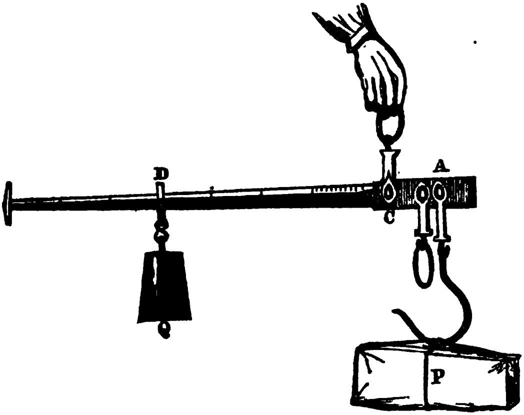

Levers of the second class occur less frequently.

An oar is an example; the water is the fulcrum, the boat is the weight, and the hand the power. A pair of nut-crackers is a double

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What is said of the steelyard? Describe the figure. Give examples of levers of the second class. Describe fig. 123.

lever of this class; and a door moving on its hinges, and a wheelbarrow, are also examples.

In levers of the third class, the power being nearer the fulcrum, is always greater than the weight. On account of this mechanical disadvantage, it is used only when considerable velocity is required, or the resistance is small. Fig. 128 represents such a lever, *WF*, moving on a hinge as a fulcrum; it is plain that the power *P*, moves through a small arc, and the weight through a large one, and since they are described in the same time, the velocity of the power is less than that of the weight.

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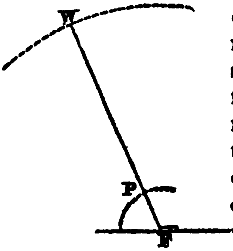

The common fire-tongs, sugar-tongs, and sheep-shears, are double levers of this class. The most striking illustrations of this class of levers are seen in the animal kingdom. The compact form and beautiful symmetry of animals, depend on the fact that their limbs are such levers. The socket of the bone *a*, fig. 124, is the fulcrum; a strong muscle attached near the socket *c* is the power, and the weight of the limb, and whatever resistance *W* may oppose its motion, is the weight. The fore-arm and hand are raised through a space of one foot, by the contraction of a muscle applied near the elbow, moving through less than $\frac{1}{12}$th that space. The muscle, therefore, exerts 12 times the force with which the hand moves. The muscular system is the exact inversion of the system of rigging a ship. The yards are moved through small spaces with great force, by hauling in a great length of rope with small force; but the limbs are moved through great spaces with comparatively little force, by the contraction of muscles through small spaces with very great force. Examples of compound levers are seen in the ordinary platform scales. They are constructed of very various forms, but all depend upon the principles already

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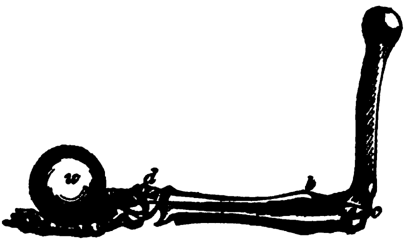
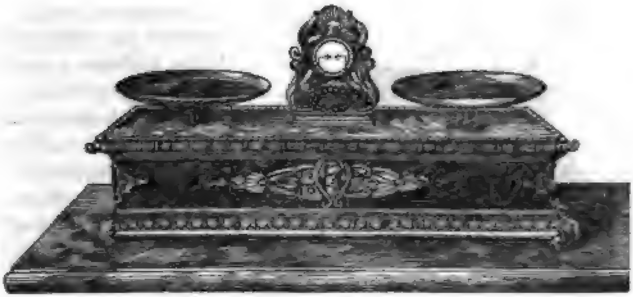


What is said of levers of the third class? Mention examples of the third class of levers? Describe fig. 124. What is said of the rigging of a ship?

explained. Fig. 125 represents a weighing machine in common use, and fig. 126 shows its interior construction. The arrangement and combination of the levers are sufficiently obvious on inspection.

125



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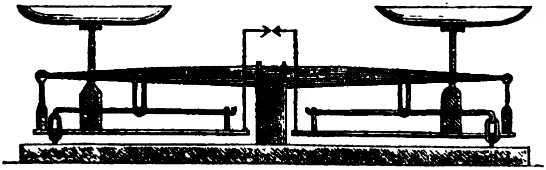

202. **The wheel and axle.**—The common lever is chiefly employed to raise weights through small spaces, by a succession of short intermitting efforts. After the weight has been raised, it must be supported in its new position, until the lever can be again adjusted, to repeat the action. The wheel and axle is a modification of the lever, which corrects this defect; and, since it converts the intermitting action of the lever into a continuous motion, it is sometimes called the perpetual lever.

This machine consists of a cylinder called the axle, turning on a centre, and connected with a wheel of much greater diameter. The power is applied to the circumference of the wheel, and the weight is attached to a rope, wound around the axle in a contrary

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Describe the weighing machine, fig. 125. 202. What is said of the wheel and axle? What does this machine consist of? What is the capstan?

direction. Instead of the whole wheel, the power may be applied to a handle named a winch, or to one or more spokes inserted in the axle. When the axle is horizontal, the machine is called a windlass, fig. 127; when it is vertical, it forms the capstan, fig. 128, used on shipboard, chiefly to raise the anchor. The head of the capstan is generally circular, and is pierced with holes, in each of which a lever can be placed, so that many men can work at the same time, exerting a great force, as is often necessary is raising an anchor.

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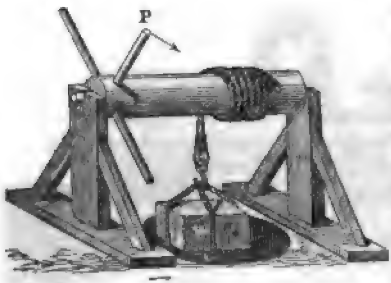

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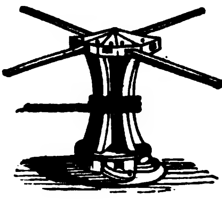

The law of equilibrium is the same as in the lever. Draw from the centre, or fulcrum *c*, fig. 129, the straight lines *c b* and *c a*, or *c a′*, to the points on which the weight and power act; *a c b*, or *a′ c b*, is evidently a lever of the first class, in which the short arm *c b* is the radius of the axle, and *c a*, or *c a′*, the long arm, is the radius of the wheel. Hence,

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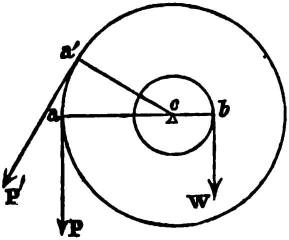

$$P \times ac = W \times cb$$

Or

$$P : W :: cb : ac$$

The wheel and axle is in equilibrium, when the power is to the weight as the radius of the axle is to the radius of the wheel.

In one revolution of the machine, the power descends through a space equal to the circumference of the wheel, and the weight is raised through a space equal to the circumference of the axle;

When are the wheel and axle in equilibrium? What is said of the relation of the power to the weight?

hence the power and weight are inversely as their velocities, or the spaces they describe.

203. **Trains of wheel-work.**—The efficiency of this machine is augmented by diminishing the thickness of the axle, or by increasing the diameter of the wheel. But if a very great power is required, either the axle would become too small to sustain the weight, or the wheel must be made inconveniently large. In this case a combination of wheels and axles may be employed. Such a system corresponds to the compound lever, and has the same law of equilibrium. The power being applied to the first wheel, transmits its effect to the first axle; this acts on the second wheel, which transfers the effect to the second axle, &c., until the force, transmitted through the series in this order, arrives at the last axle, where it encounters the resistance. In equilibrium, the power multiplied into the continued product of the radii of all the wheels, is equal to the weight multiplied into the continued product of all the axles.

Trains of wheel-work are connected by an endless band, or by cogs raised on the surfaces of the wheels and axles. Cogs on the wheel are called teeth, and those on the axle are called leaves; the axle itself is named a pinion. The number of teeth on the wheels and leaves on the pinions, is proportional to their circumferences, and also to their radii. Hence, the number of teeth and leaves is substituted for the radii of the wheels and axles, and the law of equilibrium is stated as follows. The power multiplied into the product of the number of teeth of all the wheels, is equal to the weight multiplied into the product of the number of leaves in all the pinions.

204. **Analysis of a train of wheelwork.**—A system of wheels is represented in fig. 180. If the number of leaves in *b*, the pinion of the first wheel, is one-sixth of the number of teeth on the second wheel, *e*, the wheel will be turned once by every six turns of the pinion. Let the second pinion, *c*, have the same relation to the third wheel, *f*; then the first wheel will revolve 36 times while the third revolves once; and the radius of *a*, the wheel to which the power is applied, being 3 times the radius of

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203. How is the efficiency of the wheel and axle augmented? What is said of trains of wheel-work? How are trains of wheel-work connected? What are teeth, leaves, pinions? How is the law of equilibrium stated? 204. Give the analysis of the train of wheel-work represented in the figure.

d, the axle which sustains the weight, the velocity of the power is 3 × 36 = 108 times the velocity of the weight. Or,

$$P : W : : 1 : 108$$

Combinations of wheel-work are employed either to concentrate, or to diffuse force; either to set heavy loads in motion by means of a small power, or to produce a high velocity by exerting a considerable power. In the first case, the power is applied to the first wheel of the series, and is transmitted in the order already described. In the second instance, this arrangement must be reversed; the power must exert itself on the first pinion, in order to produce rapid revolution of the last wheel. The crane for hoisting goods, is an example of the first kind; the watch is an instance of the second.

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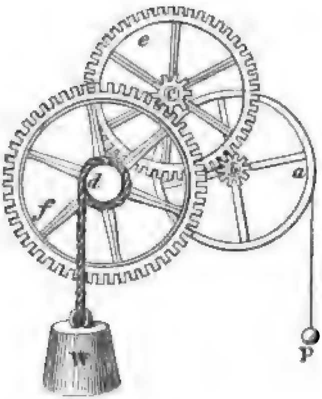

205. **The pulley.—Fixed pulley.**—The usual form of this machine is a small wheel, turning on its axis, and having a groove on its edge, to admit a flexible rope or chain. In the simple fixed pulley, fig. 131, there is no mechanical advantage, except that which may arise from changing the direction of the power. Whatever force is exerted at *P*, is transmitted, without increase or diminution, to the resistance at the other end of the cord. From the axis *C*, draw *C a* and *C b*, radii of the wheel, at right angles to the direction of the forces; *a C b* represents a lever of the first class, with equal arms; hence, in equilibrium, the power and weight must be equal, and they describe equal spaces.

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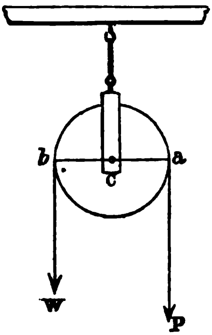

For what are combinations of wheel-work employed? Give examples of such use. 205. What is a pulley?

206. Movable pulley.—When the block or frame is not fixed, the pulley is said to be movable. The weight is suspended from the axis of the movable pulley, and the cord is fastened at one end, and passing over a fixed pulley, is acted on by the power at the other. In this arrangement, fig. 132, it is plain that the weight is supported equally by the power and the beam at *D*. For the pulley acts as a lever of the second class, whose arms are to each other as 1 : 2; the fulcrum is at *b*, *b c* is the leverage of the weight, and *b a* the leverage of the power. The diameter *b a* is twice the radius *b c*, therefore equilibrium will obtain when the power is equal to one-half of the weight: *i. e.*—

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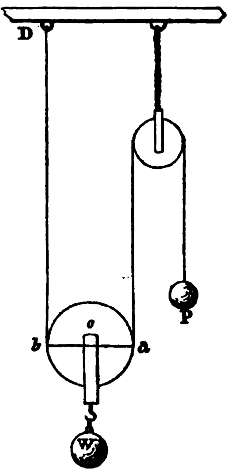

$$P : W :: b\,c : b\,a$$
$$:: \ 1 : 2$$

therefore,

$$P = \frac{W}{2}.$$

To raise the weight one foot, each side of the cord must be shortened one foot, and the power, consequently, passes over two feet. The space traversed by the power, is twice the space described by the weight.

207. Compound pulleys.—Sometimes compound pulleys are used, each consisting of a block which contains two or more single pulleys, generally placed side by side, in separate mortices of the block. Such an arrangement is shown in fig. 133. The weight is attached to the movable block, and the fixed one serves only to give the power the required direction. The weight is divided equally among the pulleys of the movable block; and as we have seen that the power required to sustain a given weight

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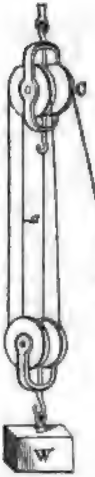
What is said of the single fixed pulley? When is the pulley in equilibrium? 206. What is a movable pulley? What is the general arrangement? When will there be equilibrium? What is the relation between the spaces traversed by the power and the weight? 207. What is a compound pulley?

is diminished one-half by a single movable pulley, it follows, that in such a system equilibrium will obtain, when the power is equal to the weight divided by twice the number of movable pulleys.

133



$$P : W : : 1 : 2n$$

Or

$$P = \frac{W}{2n}$$

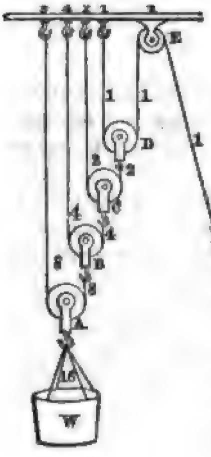
In this system, as in the single movable pulley, the space through which the weight is raised, is as much less than the space through which the power descends, as the weight is greater than the power.

$P : W : :$ velocity of weight : velocity of power.

If the power is pulled through 4 feet, fig. 133, each division of the cord in which the movable block hangs, will be shortened one foot, and the weight raised one foot.

Another system of pulleys is represented in fig. 134. In this arrangement, each pulley hangs by a separate cord, one end of which is attached to a fixed support, and the other to the adjacent pulley. The effect of the power is rapidly augmented, being doubled by each movable pulley added to the system. The numbers placed near the cords, show what part of the weight is sustained by each, and by each pulley. Such a system, however, is of little practical use, on account of its limited range. In the common block system, fig. 133, the motion may continue until the movable block touches the fixed one; but in this, only till D and E come together, at which time A will have been raised only ⅛th of that distance.

134



208. **The inclined plane.**—This mechan-

Describe the figure. When will equilibrium obtain? What is the relation between the spaces traversed by the power and the weight? Describe fig. 134. What of the practical value of such a system?

ical power is commonly used, whenever heavy loads, especially such as may be rolled, are to be raised a moderate height. In this way casks are moved in and out of cellars, and loaded upon carts. The common dray is itself an inclined plane. Suppose a cask weighing 500 lbs. is to be raised 4 feet by means of a plank 12 feet long; it is plain, that while the cask ascends only four feet, the power must exert itself through 12 feet, and hence, 12 : 4 : : 500 : 166⅔, the force necessary to roll the cask.

In mechanics, the inclined plane is a hard, smooth surface, inclined obliquely to the resistance. The length of the plane is *A C*, fig. 135, *A B* its height, and *B C* its base. The power may be applied,

a—In a direction parallel to the length;
b—Or parallel to the base;
c—Or in any other direction.

In each case, the condition of equilibrium may be derived from the equilibrium of the lever.

209. **Application of the power parallel to the length of the inclined plane.**—When a body is placed upon an inclined plane, fig. 135, its weight, which is the resistance to be overcome, acts in the direction of the force of gravity, in the perpendicular line *a W*. Let the power act in the direction *a P*, parallel to *A C;* then from *c*, the point where the body touches the planes, draw *c b* and *c a*, perpendicular to the directions of the weight and power; *a c b* is a bent lever, having its fulcrum at *c*, and therefore,

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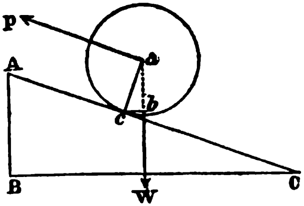

$$P : W :: b\,c : a\,b$$

and since the triangles *a b c* and *A B C*, are simiiar,

$$P : W :: A\,B : A\,C,$$

Or

$$P = W \times \frac{A\,B}{A\,C}$$

If the direction of the power is parallel to the inclined plane, equilibrium will obtain, when the power is to the weight, as the

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What is said of the common block system? 208. What is said of the inclined plane? Mention the example of the cask. What is the inclined plane in mechanics?

height of the plane is to its length. While the weight is raised through a space equal to the vertical height of the plane, the power must move through a space equal to its length. If the length of a plane is 10 feet, and its height 2 feet, P must move 10 feet, while W is raised 2 feet; hence the power and weight are inversely as their velocities.

210. **Application of the power parallel to the base of the inclined plane.**—In the second case, let the power act in the direction $a\,P$, fig. 136, parallel to $B\,C$, the base of the plane; and draw, as before, the lines $b\,a$ and $b\,c$: then $a\,b\,c$ is a bent lever, having its fulcrum at b, and equilibrium will take place when

$$P : W :: b\,c : a\,b$$

and the triangles $a\,b\,c$ and $A\,B\,C$, being similar,

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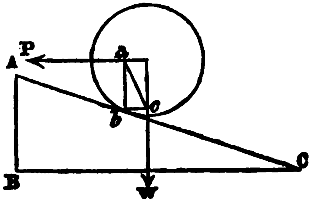

$$P : W :: A\,B : B\,C$$

Or

$$P = W \times \frac{A\,B}{B\,C}$$

If the direction of the power is parallel to the base of the plane, equilibrium will obtain, when the power is to the weight, as the height of the plance is to its base.

In this case, the space described by the power, is to the space described by the weight, as the base of the plane is to its height.

211. **Application of the power in some direction not parallel to any side of the plane.**—Lastly, let the power act in some direction not parallel to any side of the plane; for example: in the direction $a\,P$, fig. 137, draw the lines $b\,c$ and $b\,a$, perpendicular to the directions of the two forces; then, as before,

$$P : W :: b\,c : a\,b$$

What is said of the directions in which the power may be applied? 209. What is the relation when the power is applied parallel to the length of the inclined plane? When will equilibrium obtain? What is said of the power and the weight in relation to their velocities? 210. What is the relation when the power is applied parallel to the base of the inclined plane? When will equilibrium obtain? What is the relation betwen the spaces described by the weight and the power?

But as the triangles *a b c* and *A B C*, are not similar, the proportion between the arms of the lever cannot be expressed by the sides of the plane.

212. **Effect of the power applied.**—It follows from what has been said, that the effect of a given power is greater, as the height of the plane is diminished or its length increased; and that the effect is greatest when its direction is parallel to the length of the plane, for, if the power acts in any other direction, a part of its force is expended, either in increasing the pressure of the body on the plane, or in lifting the weight directly.

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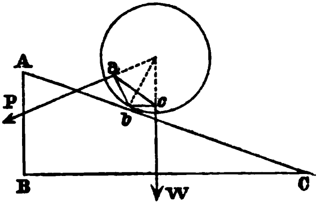

213. **The wedge.**—Instead of lifting a load by moving it along an inclined plane, the same result may be obtained by moving the plane under the load. When used in this manner, the inclined plane is called a wedge. It is customary, however, to join two planes base to base. In fig. 138, *A B* is called the back of the wedge, *A C* and *B C* its sides, and *d C* its length. The power is applied to the back of the wedge, so as to drive it between two bodies, and overcome their resistance.

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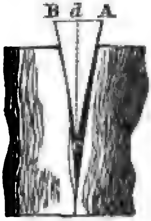

214. **Resistance to be overcome.**—The resistance may act at right angles to the length or to the sides of the wedge. In the first case, it resembles an inclined plane, when the power is parallel to the base; and hence the forces will be in equilibrium when the power is to the resistance as the back of the wedge is to its length. In the second case, it is similar to a plane when the power is parallel to the length; and therefore in equilibrium, the power is to the resistance as the back of the wedge to its side.

The power is supposed to move through a space equal to the length of the wedge, while the resistance yields to the extent of its breadth.

215. **Application of the wedge.**—As a mechanical power, the

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211. What is the relation when the power is applied in some direction not parallel to any side of the plane? 212. What is said of the effect of the power applied? 213. What is said of the wedge? What is its common form? Describe fig. 138. 214. What is said of the resistance to be overcome? What of the movement of the power and the resistance?

wedge is used only where great force is to be exerted in a limited space. In oil-mills, the seeds from which vegetable oils are obtained are crushed and compressed with enormous force by means of a wedge. It is everywhere employed to split masses of stone and timber. The edges of all cutting tools, as saws, knives, chisels, razors, shears, &c., and the points of piercing instruments, as awls, nails, pins, needles, &c., are modified wedges. Chisels intended to cut wood, have their edge at an angle of about 30°; for cutting iron, from 50° to 60°; and for brass, about 80° to 90°. The softer or more yielding the substance to be divided is, the more acute the wedge may be constructed. In general, tools which are urged by pressure, admit of being sharper than those which are driven by a blow.

The theory of the wedge gives but very little aid in estimating its effects, as it takes no account of friction, which so largely modifies the results, and the proportion between a pressure and a blow cannot be defined.

216. **The screw.**—This machine has the same relation to the ordinary inclined plane, as a spiral staircase to a straight one. This relation is shown in fig. 139. By means of the corresponding letters and dotted lines, in fig. 140, the position of the different parts of an inclined plane upon a screw, may be distinctly seen. Let an inclined plane be wound around a cylinder, fig. 139, the length of the plane will form the spiral line, called the thread of the screw. The distance between the threads is the height of corresponding parts of the plane. The thread projects from the surface of the cylinder, and is designed to fit into a hollow spiral, cut in the interior of a block called the nut; a lever is also

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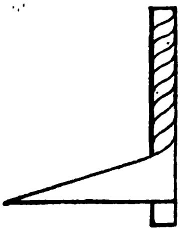

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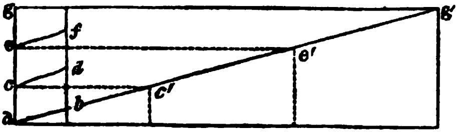

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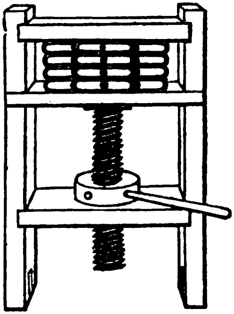
215. Mention applications of the wedge. What is said of cutting tools and piercing instruments? Give the angle of inclination of the edges of chisels for cutting wood, iron, and brass. What is said of the effects of the wedge and theory? 216. What is said of the screw?

fixed in the head of the cylinder to which the power is applied, fig. 141. The combining of these parts forms the mechanical power which has received the name of the screw.

141



In working the screw, the resistance acts on the inclined face of the thread, and the power parallel to the base of the screw. This corresponds to the case in which the direction of the power is parallel to the base of the inclined plane. Equilibrium will, therefore, take place when the power is to the resistance as the distance between the threads of the screw is to the circumference described by the power.

$$P : W :: h : 2r\pi$$

$$P = W \times \frac{h}{2r\pi}$$

h being the distance between the threads, and r the radius of the screw.

During each revolution, the power describes a circle, whose circumference depends on the length of the lever, but the end of the screw advances only the distance between two threads; thus in this, as in all cases of the use of machines, what is gained in power, is lost in velocity.

217. **Mechanical efficiency of the screw.**—The mechanical efficiency of the screw is augmented, either by increasing the length of the lever, or by lessening the distance between the threads. If the threads of a screw are ½ of an inch apart, and the power describes a circle of 5 feet, (120 half-inches,) circumference, a power of 1 lb. will balance a resistance of 120 lbs; if the threads are ¼ inch apart, 1 lb. will balance 240 lbs., the efficiency being doubled.

218. **Applications of the screw.**—As the screw exerts great

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How is the screw moved? Where does the resistance act? To what does this correspond in the inclined plane? When will equilibrium take place? What is said of the power and the screw during each revolution? 217. How is the mechanical efficiency of the screw augmented? Give an example.

pressures through small spaces, it receives numerous applications in presses of all kinds, as in extracting liquids and juices from solid bodies and in compressing soft and light substances, as cotton and hay, into a convenient bulk for transportation.

Impediments to Motion.

219. **Passive resistances.**—Besides those resistances which a machine is designed to overcome, there are certain others which arise during the movement of the machine, and oppose its useful action by destroying more or less of the moving power. These forces are designated by the general name of *passive resistances*, or impediments to motion.

Several kinds are distinguished:

1st.—When we attempt to cause one body to slide over another, a resistance is experienced, so that it is necessary to use a certain degree of force to commence the sliding, and also to continue the motion after it has been begun. This is the resistance called *sliding friction*, or simply friction.

2d.—When a cylindrical body is rolled on a plane surface, the movement is opposed by a force called the *rolling friction*. It is seen, for example, in the rolling of carriage wheels on the ground.

3d.—The ropes and chains which enter into the composition of some machines, are supposed, in theory, to be perfectly flexible, but as they are not so, a considerable loss of power is caused by their stiffness, or *imperfect flexibility*.

4th.—The movements of all machines take place either in air or water, and the particles of these fluids which come in contact with the machine, are continually set in motion, which can only happen at the expense of the moving power. This is called the *resistance of fluids*.

220. **Sliding friction.**—If the surfaces of bodies were perfectly hard and smooth, they would slide upon each other without any resistance. But the most highly polished surfaces are, really, (as they appear under the microscope,) full of minute projections and cavities, which fit in each other when two surfaces are brought into contact. The force required to overcome the rough-

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218. Mention applications of the screw. 219. What is said of passive resistances? What other name is given to them? Mention the different kinds of passive resistances.

ness and consequent adhesion of surfaces, is the measure of friction. This weight, divided by the weight of the body, forms a fraction which is called the co-efficient of the friction.

221. **Starting friction; friction during motion.**—The amount of force necessary to commence the motion of two bodies, sliding on each other, is, in most cases, greater than the force required to continue the movement uniformly, after it has been begun; hence this resistance is distinguished into two kinds, starting friction, and friction during motion. They are also called statical and dynamical friction; and Whewell proposes to name the former *striction*, reserving the word friction for the latter. However named, the laws of each can be determined only by experiment.

222. **Coulomb's apparatus for determining starting friction.**—Different observers are by no means agreed in respect to all the laws of friction; we shall here follow the results obtained in 1781, by the celebrated French philosopher and mathematician, Coulomb. In 1831, Morin, by command of the French government, repeated and enlarged the experiments of Coulomb, usually verifying his general conclusions. The principal apparatus used by Coulomb, is represented in fig. 142. It consists of a horizontal table; a box, *A*, to receive the weights used to produce the different pressures; a pan, *D*, on which were placed the weights to drag the box along the table by means of a cord passing over a pulley. The box was mounted in slides, of the same substance on which the experiment was to be made, and corresponding slips of the same, or a different substance, were placed under the sliders on the table.

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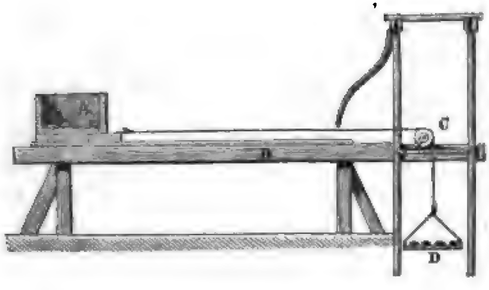

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220. What is said of sliding friction? 221. What is said of starting friction and friction during motion? What other names have been proposed for them? 222. What is said of Coulomb and Morin? Describe the apparatus Coulomb employed.

The amount of the weight required to be placed in *D*, to move the box from a state of rest, is the measure of starting friction; and the weight necessary to continue the movements uniformly, is the measure of friction during motion.

223. **Results of Coulomb's experiments.**—Without detailing the experiments, it will be sufficient to state their general results, embraced in the following laws.

Friction during movement is,

1st.—Proportional to the pressure exerted upon the sliding surfaces.

2d.—Independent of the extent of the surfaces in contact.

3d.—Independent of the velocity of the movement.

4th.—Greater between surfaces of the same than surfaces of different materials.

5th.—Greatest between rough surfaces, and is diminished by polishing, and usually by the use of suitable unguents.

Friction at starting is,

1st.—Proportional to pressure.

2d.—Independent of extent of surface.

3d.—Generally increased by polishing the surfaces.

The friction at starting, and during the movement, are the same, when the sliding surfaces are hard, like the metals; but if the bodies are compressible, like wood, the starting friction is much the greatest. When at least one of the surfaces is compressible, the resistance is not always the same, but varies according to the time the surfaces have been in contact. If wood slides on wood, the starting friction attains its greatest intensity in two or three minutes; but if the sliding surfaces are wood and metals, the greatest intensity is not reached for a much longer time, several hours, and sometimes several days. But after a certain time has elapsed, the starting friction is no longer augmented by lengthening the time of contact.

It appears strange at first, and contrary to our previous ideas, that the friction at starting, and during movement, should not be increased by enlarging the surfaces in contact, and *vice versa*. The explanation is this. Friction is proportional to pressure; if, therefore, two bodies have the same weight, and one has twice

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223. Give the results of Coulomb's experiments of friction during movement. Of friction at starting. What is said of the frictions when the sliding surfaces are alike? What when one surface is compressible? What when wood slides upon wood? When wood and metals form the sliding surfaces?

the surface of the other, the weight, being equally distributed on each surface, will be twice as great on each point of the surface of the first body, as on each point of the second, and consequently, the friction at each point of the first, is twice the friction at each point of the second, and the whole friction must be the same for each body. This law, however, does not hold good in extreme cases.

With the same pressure, the friction varies exceedingly, according to the nature of the surfaces in contact. The following table shows the ratio of friction in several cases, the pressure being 100.

Surfaces in contact.	Ratio of friction to pressure.	
	At starting.	In motion.
Wood upon wood, ...	0·50	0·36
" " " with coating of soap,	0·36	0·14
" " " " " of tallow,	0·19	0·07
" " metals, ...	0·60	0·42
" " " with coating of tallow,	0·12	0·08
Leather bands on wood, ...	0·68	0·45
" " wet, ...	0·87	0·33
Metals on metals, ...	0·18	0·18
" " " with coat. of olive oil,	0·12	0·07

224. **Rolling friction.**—The resistance experienced in rolling a cylinder along a plane surface, is distinct in character from the friction produced in sliding the cylinder, and very much less in amount. In wood rolling on wood, the proportion of resistance to pressure is from 16, or 6, to 1000, while the sliding friction in the same case, would be as 5 to 10, or 36 to 100, according to the kind of sliding friction. The resistance of rolling friction arises from a slight change of form produced in the body, and the surface on which it moves, and corresponding to the amount of pressure. The cylinder is flattened, and the plane depressed, so that the moving force is exerted, in continually moving the body up a very minute inclined plane.

225. **Coulomb's apparatus for determining rolling friction.**—This apparatus employed by Coulomb, consisted of two bars,

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What is said of the amount of friction when the surfaces in contact are enlarged? Mention the ratio of friction to pressure at starting and during motion of wood upon wood, with coating of soap and tallow. Of wood upon metals, &c. 224. What is said of rolling friction? What is the relation of resistance to pressure in wood rolling on wood? From what does rolling friction arise?

horizontal and parallel, with a space between them, fig. 143. A cylinder of the same, or a different substance, was placed transversely across the bars, and loaded with any required pressure by hanging strings upon it, carrying equal weights at their extremities. Another string wound several times around the middle of the cylinder, carried a pan *c*, to receive the weight necessary to produce motion. It is evident that this weight acted always at the extremity of the radius of the cylinder as a lever.

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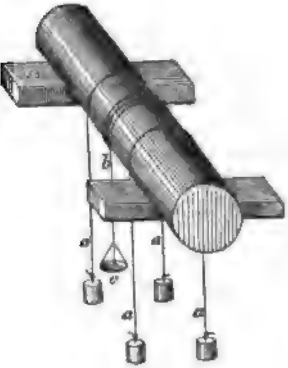

226. **Results of Coulomb's experiments.**—From the experiments were derived the following laws:

The friction of rolling bodies is,

1st.—Proportional to pressure.

2d.—Independent of velocity, of the diameter of the cylinder and of the extent of the surfaces in contact.

3d.—Greater when the substances are the same than when they are different.

4th.—Not diminished by coatings of grease, but is affected by the polish of the surfaces.

If the force which produces the movement, instead of being applied always at the same arm of the lever, fig. 143, were applied horizontally at the centre of the cylinder, or at the upper extremity of its vertical diameter, it would be inversely proportional to the diameter.

The friction of the axle of a wheel, whether the axle itself turns, or the wheel on the axle, is different from rolling friction. It is somewhat less than sliding friction, but obeys the same laws. The friction of axles may be reduced one-half or one-quarter its original amount by the use of proper unguents.

227. **Mr. Babbage's experiment.**—Mr. Babbage cites an in-

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225. Describe Coulomb's apparatus for determining rolling friction. 226. Give the results of Coulomb's experiments. What would be the result if the power were applied horizontally at the centre of the cylinder? What is said of friction at the axle of a wheel?

structive experiment to illustrate the decrease of friction. A block of stone weighing 1080 lbs. was drawn on the surface of a rock by a force of 758 lbs.; placed on a wooden sledge, it was drawn on a wooden floor by a force of 606 lbs.; when both wooden surfaces were greased, 182 lbs. was sufficient; and when the block was mounted on wooden rollers of three inches diameter, a force of only 28 lbs. was required to move it.

228. **Advantages derived from friction.**—The advantages arising from friction are infinitely greater than the loss of power which it occasions. Without this property of matter, it would be equally impossible to make or use machines, for nothing could be nailed, or screwed, or tied together, or grasped securely in the hand. From the difficulty of walking on very smooth ice, we may infer how useless would be the effort to move, if our feet met no resistance whatever.

229. **Rigidity of ropes.**—When ropes are used to transmit force, their stiffness occasions a considerable loss of power, amounting, in some combinations of pulleys, to two-thirds of the whole power. The amount of the loss from this cause is modified by many external circumstances, such as the dampness of the cordage, its quality, and the manner in which it is made. In general, the resistance of ropes is,

1st.—Proportional to the tension to which they are subjected.

2d.—It increases with the thickness, and is greatest in those that have been strongly twisted.

3d.—It is inversely proportional to the diameter of the wheel or cylinder around which the ropes are bent.

When a rope is wound more than once round a cylinder, the resistance increases in a geometrical ratio. A wet hemp rope, wound around a cylinder of oak by a power of 1 cwt., will sustain with 1, 2, and 3 coils respectively, a force of 8 cwt., 3¼ tons, and 25¼ tons.

230. **Resistances of fluids.**—The resistance which a moving body meets in air and water, is an effect of the transfer of motion from the solid to the particles of the fluid. For the moving body must constantly displace a part of the fluid equal to its own bulk, and the motion thus communicated, is so much loss of the motive

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227. Mention Mr. Babbage's experiment. 228. Mention some of the advantages arising from friction. 229. What is said of the rigidity of ropes? What are the laws for the resistance of ropes? What is the resistance when a rope is wound more than once around a cylinder?

power. When other circumstances are the same, the denser the medium, the greater will be the resistance which it offers. Newton demonstrated, that if a spherical body moves in a medium at rest, and whose density is the same as its own, it will lose half of its motion before it has described a space equal to twice its diameter. The resistance encountered by a body moving in water, is 800 times greater than if it were moving with the same velocity in air; for water, being 800 times more dense than air, the body must displace, and communicate its own motion, to 800 times as much matter in the same time.

The resistance also depends upon the extent and form of the surface which is directly opposed to the resistance, *i. e.*, at right angles to the direction of the motion. A body with a pointed, wedge-shaped, or curved surface, is less opposed than one whose surface is flat and broad.

The resistance increases as the square of the velocity; for if the velocity is doubled, the loss of motion must be quadrupled, because there is twice as much fluid to be moved in the same time, and it has also to be moved twice as fast. Again, let the velocity be trebled, then the body will meet three times as many particles of the fluid in the same time, and communicate three times the velocity; therefore the resistance is $3 \times 3 = 9 = 3^2$.

Bodies having the same figure and density, overcome the resistance of fluids more easily, in proportion to their size. In cannon-balls, for example, the extent of surface to which the resistance is proportional, increases as the square of the diameter, while the weight or power to overcome resistance, increases as the cube of the diameter. If two balls have diameters in the ratio of 2 : 3, the resistances which they will encounter at the same velocity of projection, will be in the ratio of 4 : 9, and their moving force in the ratio of 8 : 27.

231. **Actual and theoretical velocities.**—In consequence of these impediments to motion, the actual movements of bodies are materially different from the theoretical motions explained in previous chapters. The motion of falling bodies is very far from being

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230. What is the resistance which a moving body meets in air and water an effect of? What did Newton demonstrate? How much greater resistance is offered to a body moving in water than in air with the same velocity? How does the form of a body effect the resistance? What is the relation between the density and the velocity? Give an example. When bodies have the same figure and density but are of different sizes, what is said of the resistance of fluids? Give the example of the cannon-balls.

uniformly accelerated, (§ 152,) nor do all bodies fall with equal rapidity, as theory requires, and as was seen to be true in the guinea and feather experiment, (§ 157.) The resistance of the air, which is very small at first, rapidly increases, and after a certain time becomes equal to the force of gravity, when the body will no longer be accelerated, but move uniformly through the remainder of its descent. The descent of bodies on inclined planes and curves, deviates still more from uniformly accelerated motion, since the effect of friction is added to the resistance of the air.

232. **Ballistic curve.**—A still greater difference is observed between the actual and theoretical motions of projectiles. Instead of describing a parabola, fig. 144, *A E B*, the projectile actually describes the curve *A C D*, called the ballistic curve, which never attains so great a vertical height, or so long a range as the corresponding parabola, and which, towards the end of its course, continually approaches the perpendicular, *E F.* A four pound shot, which flies 6437 feet in the air, would traverse in a vacuum, a space of 23,226 feet.

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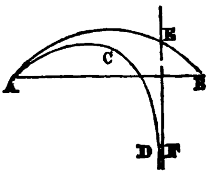

But, as in the case of friction, the benefits resulting from this state of things overpay the disadvantages. Fish could not swim, nor birds fly, were it not for the resistances of the media they inhabit. The paddle-wheels of a steamer would not move it, nor its rudder guide its course, if they met no resistance to their movements. And we can very well dispense with a perfect theory of projectiles, if thereby the rain is prevented from descending with the destructive velocity of hail-stones.

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231. What is said of actual and theoretical velocities? What is said of the motion of falling bodies? What is said of the descent of bodies on inclined planes and curves? 232. What is said of the motion of projectiles? What is the form of the ballistic curve? What are among the advantages resulting from resistance to motion?

HYDROSTATICS.

283. **Hydrodynamics** treats of the peculiarities of state and motion among fluid bodies; it may be divided into *hydrostatics*, *hydraulics*, *pneumatics*, and *acoustics*.

284. **Hydrostatics** treats of the general properties of fluids at rest, their nature, gravity, pressure, &c. Fluids are bodies in which the reciprocal attraction of the molecules is in equilibrium with the elastic force of heat. Their particles have perfect mobility, freely moving among one another, and their masses assume always the form of the vessels containing them.

285. **Elastic and non-elastic fluids.**—Fluids are divided into elastic and non-elastic, but this is not a well-defined distinction, for we cannot draw a perfect line of demarkation between those fluids which are but slightly compressible and elastic, as water, and those which, like air and the gases, are compressible in a high degree. Fluids of one class have properties common to the other, with but slight modifications. We shall therefore first treat of the physical properties of fluids generally, reserving for after consideration the properties of the more eminently elastic fluids or gases.

286. **Compressibility.**—Liquids were, for a long time, considered as absolutely incompressible. But the researches of Canton, in 1761, Oersted, in 1823, and others, have proved that all liquids are slightly compressible. The piezometer (*piezo*, to press, *and metron*, a measure,) is an instrument designed to measure the compressibility of liquids. Oersted's apparatus, fig. 145, consistsof a strongglass cylinder; twenty-four or twenty-five inches in height, mounted on a stand, the upper part is accurately closed by a brass cap, through which passes the funnel tube *R*, to supply the vessel with water, and a cylinder, furnished with a piston, moving by the screw *P*. In the interior is a vessel *A*, containing the liquid to be compressed, having a capillary tube at its upper part, which bends and descends to the mercury, *O*, contained in the lower part of the vessel. This capillary tube is

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283. What of hydrodynamics? Into what may it be divided? 284. What does hydrostatics treat of? What are fluids? 285. Into what classes may fluids be divided? What is said of these classes? 286. What is said of the compressibility of liquids?

subdivided into equal parts, and the number of these parts the vessel *A*, can contain, is accurately determined. There is also in the interior of the cylinder, a tube of glass, furnished with a graduated scale; this tube is closed at its upper end, and has its lower end immersed in the mercury, *O*. This instrument is called a manometer, and is, when at rest, filled with air. In order to experiment with this apparatus, we fill the vessel *A*, with the liquid to be compressed, and by means of the funnel *R*, fill the cylinder with water, having previously placed mercury in its lower part. Turning the screw *P*, we make the piston descend; in consequence, the air in the tube, *B* is compressed, and the mercury is elevated; thedegree of elevation shows the amount of pressure, (the number of pounds or atmospheres); at the same time, the mercury rises in the capillary tube, and gives the measure of the compression of the liquid in *A*. Supposing each division of the capillary tube held but a millionth part as much as the vessel *A*, then if the liquid to be compressed was water, (at the pressure of one atmosphere,) we should observe the mercury to rise between 49 and 50 divisions. There is one correction to be made of the observations obtained by this instrument; it might be supposed that the capacity of *A*, would be invariable, the exterior and interior walls being compressed equally by the liquid, but it is not so; the interior capacity of the vase undergoes the same diminution as would a body of glass of the same form and volume, submitted to the same pressure. This diminution amounts to about 33 ten millionths, ($\frac{33}{10000000}$) of the primitive volume, for one atmosphere. The corrected results of the researches of M. M. Culloden, and Sturm, are as

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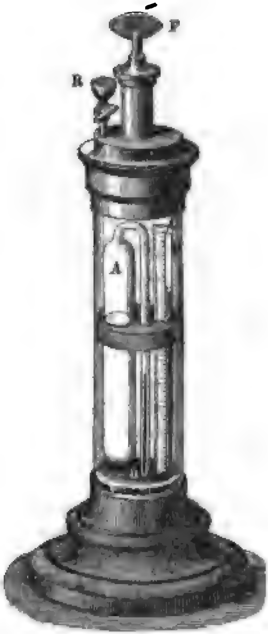

Describe the piezometer. Mention the compressibility of different liquids. What is said of M. Aimé's experiments?

follows: at the temperature of 32° F., and with a pressure of one atmosphere.

Mercury was compressed	5·03	parts in a million.
Water, deprived of air, was compressed	51·3	" " "
" not " " " " "	49·5	" " "
Sulphuric ether " "	13·3	" " "
Acetic acid " "	42·2	" " "
Sulphuric acid " "	32·	" " "
Oil of turpentine " "	78·	" " "

The contraction of liquids is, within certain limits, in direct proportion to the pressure. With the piezometer mentioned above, experiments with a pressure as great as 30 atmospheres have been made. M. Aimé has, with a different form of apparatus, compressed liquids under the enormous pressure of 220 atmospheres.

237. **Elasticity.**—As liquids are slightly compressible, it follows that they must have a certain elasticity. This is shown upon removing the pressure from a compressed liquid; it immediately returns to its former volume. Liquids have also elasticity from the stability of form they may take.

Drops of liquid, placed upon a surface they do not wet, become spheres; if these be struck, they flatten, but immediately resume the spherical form, as with small particles of mercury or drops of water covered with dust. Again, this is shown when we attempt to remove a drop of water, or other liquid, from a surface for which it has strong attraction; the drop will elongate as we apply the separating force, but immediately resumes its former position and shape, when it is left to itself, because of its elasticity.

238. **Equality of pressure.—Liquids transmit pressure equally in all directions.**—Liquids transmit, in all directions and with the same intensity, the pressure exerted on any point of their mass. In order to comprehend this statement, let fig. 146 be a vessel filled with a liquid, and furnished with a number of equal cylinders, in each of which there is a piston. The vessel, as also the liquid, are supposed to be without weight, consequently, none of the pistons have a tendency to move. If we apply a pressure to the piston *A*, it will be forced inwards, and the other pistons, *B*, *C*, *D*, and *E*, of equal area, will each be forced outwards

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237. What is said of the elasticity of liquids? Mention examples.
238. What is said of the equality of pressure of liquids?

with the same pressure. So that if the piston A was pressed inwards with a force of one pound, it would be found necessary to apply a force of one pound to each of the other pistons, in order to keep them in their place. If the area of *B* and *C* was two or three times that of *A*, then the pressure upon them would be two or three times as great. We cannot perfectly demonstrate, that liquids transmit pressure *equally* in all directions, (because we cannot obtain for experiment, as would be necessary, liquids without weight, and pistons working without friction,) but we can show that this pressure is exerted in all directions, by the simple apparatus, fig. 147, consisting of a cylinder, furnished with a piston and terminated by a sphere; on this sphere are placed small tubes, jutting out in all directions; upon filling the sphere and cylinder with water, and pressing upon the piston, the water is forced out from each of the tubes.

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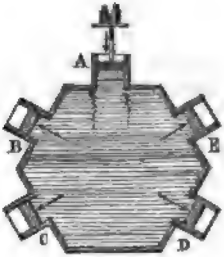

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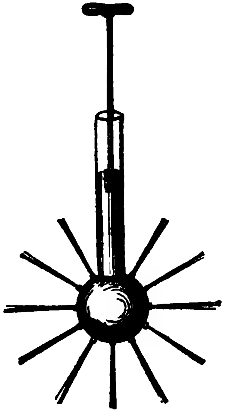

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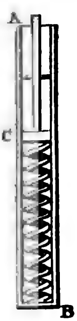

239. **Downward pressure of a liquid, proportioned to its depth.**—That liquids press downwards, and that this pressure increases with the depth, may be shown by the apparatus, fig. 148, consisting of a metal cylinder containing a piston, *C*, moving water tight, and resting upon a spring; if this instrument be placed vertically in a liquid, *the piston is forced in with a pressure equal to the weight of a column of the liquid, whose base is equal to the magnitude of the piston, and whose height is equal to the depth of the liquid below the surface.*

240. **Pressure on the bottom of a vessel.**—*The pressure of a*

How may this be illustrated? Why can it not be perfectly demonstrated? How may we show that liquids exert pressure in all directions? 239. What is said of the downward pressure of liquids?

liquid on the bottom of a vessel, is independent of the shape of the vessel, and is equal to the weight of a column of liquid, whose base is that of the containing vessel, and whose height is equal to that of the contained fluid.—In order to demonstrate that the pressure is independent of the form, M. Haldat contrived the apparatus, fig. 149. It consists of a tube, *A B c*, bent twice at right angles. On *A*, may be placed the vessels *M* and *P*, of equal height, but of different forms. The tube *A B c* is filled with mercury, which rises to an equal height in *A* and *c*; *M* is then placed on *A*, and filled with water; the mercury immediately rises in *c*, to a certain point, as *a*. We then replace *M* by *P*, and fill with water as before. The mercury will again rise to the point *a*, as it did when the vessel *M* was on *A*; it is evident that the pressure transmitted to the mercury in the direction *A B*, was the same, in both cases, proving, most conclusively, that the pressure does not depend upon the quantity of liquid, for the vessels *M* and *P*, differ greatly in capacity. However, the area of the base formed by the surface of the mercury, and the vertical height formed by the column of water, were the same in both cases, and upon these

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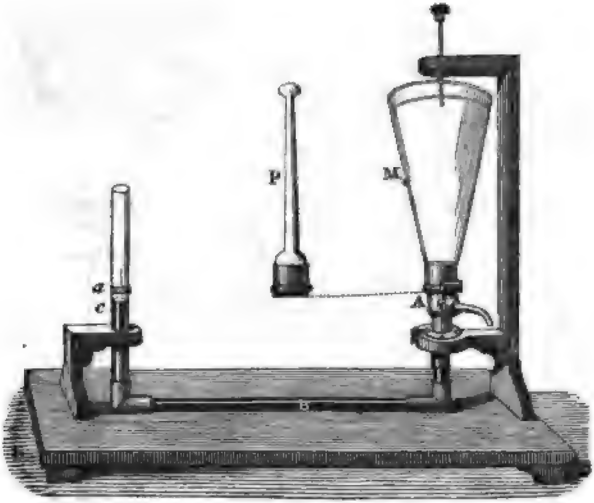

How may this be illustrated? 240. What is said of the pressure on a bottom of a vessel? Describe Haldat's apparatus. What is the pressure of a liquid in a vessel having vertical walls?

as stated above, does the pressure depend. In the case of a vessel having vertical walls, the pressure would be equal to the weight of the liquid the vessel contained.

241. **Upward pressure.**—We have shown that pressure was exerted from above, downwards; it follows, from the law of equality of pressure, (§ 238,) that a corresponding force is exerted from below, upwards. This pressure is made very manifest by the buoyancy experienced when we plunge the hand into a liquid of great density, as mercury. In order clearly to demonstrate this upward pressure, a tube of glass is taken, open at both ends, fig. 150, having at the lower end a disc of glass, *B*, which is supported by means of a thread from its centre. The whole is then placed in a vessel of water and abandoned to itself; the disc will remain attached to the end of the cylinder, because of the upward pressure of the water. If now the interior tube is carefully filled, the disc will not fall until the level of the water within the tube is the same as that in the outer vessel, which proves that the upward pressure is equal to the weight of the interior column, and therefore *the upward pressure, in any vessel, is in proportion to the height of the* liquid column.

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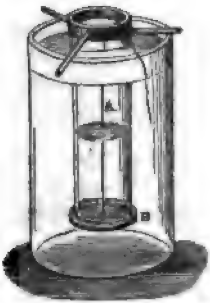

242. **Pressure on the walls.**—*The pressure of a liquid on any portion of a lateral wall, is equal to the weight of a column of liquid, which has for its base this portion of the wall, and for its height the vertical distance from its centre of gravity to the surface of the liquid.* As in fig. 151, the pressure on the point *C*, of the wall is equal to the weight of the column *A B*, for the pressure of this is communicated laterally, to all the particles lying on the same horizontal plane.

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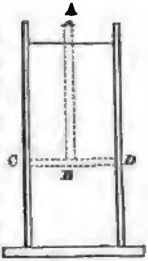

243. **Lateral pressure increases with the depth.** As the pressure of a liquid on any point of a wall, is equal to the weight of its corresponding vertical

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241. What is said of the upward pressure of a liquid? How may it be made manifest? Describe the apparatus by which it may be clearly demonstrated. 242. What is said of the pressure of a liquid on the lateral walls? Describe the figure 151.

column, therefore *the lateral pressure of a liquid in any vessel, increases with the depth*, as in fig. 152, the liquid column *A C*, pressing with a certain force on *D*, the column *E F* will press on G, with a force as much greater, as *E F* is greater than *A C*. This may be further illustrated by placing the apparatus, fig. 148, in a horizontal position, the piston will be forced in with a pressure corresponding to the depth; also, if it is placed in any position intermediate between the horizontal and vertical, the piston will be pressed in, thus proving conclusively, that pressure is exerted in all directions.

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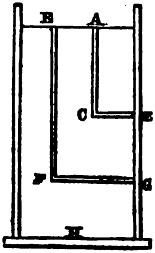

244. Total pressure on the walls.—Let us, in the vessel *A B C D*, fig. 153, have the side *A B*, divided into 10 equal parts, supposing the pressure at 1 to be one pound, then the pressure at 2 would be two pounds, at 3 three pounds, &c., as the intensity of the pressure increases directly with the depth. The average intensity of pressure would be found at the 5th division, (a point midway between the 1st and 10th,) and the total pressure on the walls would be the same as if it sustained the average intensity over the whole lateral surface, and therefore *the total pressure upon a wall of such a vessel, is equal to the weight of a column of the liquid whose base is equal to the area of the side, and whose height is equal to one-half of the depth of the liquid in the vessel*. This is true, whether the vessel be vertical or inclined outwards or inwards. In the case of a cubical vessel, this pressure on one side would be equal to one-half the weight of the liquid contained in the vessel.

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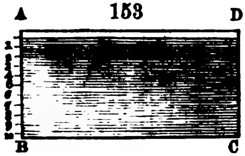

245. Total pressure on the bottom and sides of a vessel.—The total pressure exercised on the bottom and sides of a vessel, is much greater than the weight of the liquid contained in the vessel. In the case of a cubical vessel, the pressure exerted on the bottom is equal to the whole weight of the liquid, (§ 240,) the pressure exerted on each side is equal to half the weight of the liquid, (§ 244,) on the four sides, it is equal to twice its weight, consequently, *in a cubical vessel, the pressure exerted on the bottom*

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243. What is said of the lateral pressure increasing with the depth? Illustrate by the figure 152. 244. What is said of the total pressure on the walls of a vessel? 245. What is the total pressure on the bottom and sides of a vessel?

and sides, is equal to three times the weight of the contained fluid.

246. **Table,** *showing the pressure in pounds, per square inch, and square foot, produced by water at various depths.*

Depth in feet.	Pressure per square inch.	Pressure per square foot.
1	0·4328	62·3232
2	0·8656	124·6464
3	1·2984	186·9696
4	1·7312	249·2928
5	2·1640	311·6160
6	2·5968	373·9392
7	3·0296	436·2624
8	3·4624	498·5856
9	3·8952	560·9088
10	4·3280	623·2320

By aid of the above table, the pressure of water on any surface of a vessel containing it, can be determined. As, for example, the pressure of water on a square foot, at the bottom of a vessel twenty-three feet in depth; at two feet, the pressure is 124·6464; at twenty feet, ten times as much; — 1246·464; at three feet, 186·9696. 1246·464 + 186·9696 = 1433·4336, the pressure of water on a square foot of surface, at a depth of twenty-three feet.

That the pressure produced at great depths is really immense, can be shown by confining a piece of wood at great depths in the sea. The pressure forces the water into the pores, so that it will not be capable of floating afterwards. A bottle, the body of which is square, if tightly corked and lowered into the sea, will be broken by the pressure. If the body of the bottle is strong and cylindrical, the cork will be forced in. Below a certain depth, divers cannot penetrate, and the same may, perhaps, be true of fishes.

247. **The centre of pressure.**—The centre of pressure in a mass of fluid, is a point where all the elementary pressures are equally balanced, or are in equilibrium. It is always placed lower than the centre of gravity, since it would coincide with it, were it not that the lower masses of fluid were compressed by

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What if the vessel has a cubical form? 246. Give the pressure upon a square inch and square foot at the depth of 1, 2, 4, 5 and 10 feet? Determine the pressure of water on a square foot 23 feet below the surface. What facts illustrate pressure at great depths? 247. What is the centre of pressure?

those above. The position of this point is determined by calculation.

1st.—*In a vessel whose sides are parallelograms, the centre of pressure is on a line which divides into two eqaal parts the horizontal layers, at a point one-third of the distance from the lower part.* As in the vessel, fig. 154, the centre of pressure is on a line *A B*, at the point *C*, one-third of the distance from the lower part *B*.

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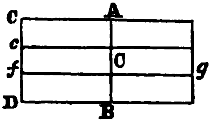

2d.—*In a triangular vessel, standing on its base, the centre of pressure is on the vertical line, reaching from the centre of the base to the apex, at a point one-fourth of the distance from the lower part.* As in fig. 155, the centre of pressure is at the point *c*, one-fourth of the vertical line *A B:* if the same vessel rests on its apex, the centre of pressure is at the point midway between the centre of the base and the apex, as in fig. 156, at the point *c*, one-half of the vertical line *A B*.

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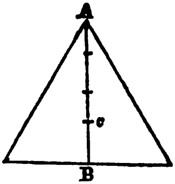

248. **Level surface of a liquid.**—That the surface of a liquid must be level, is evident from the mobility of the particles. This results from the attraction of gravitation, and also because of the fact, that when a body is free to move, its centre of gravity will descend as low as possible. Mountains do not sink and press up the intermediate valleys, because the cohesion of the particles is opposed to gravitation, but if the mountains were liquefied, the ridges would sink down, and the valleys would rise, until the whole mass would have a uniform level surface. A perfectly level surface on the earth, means one in which every particle is equi-distant from the centre, and is therefore a truly spherical surface. A terrestrial surface of large extent would show a difference of elevation of about four inches in a mile. In making a canal, therefore, in order to have it level, there must be this deduction from the terrestrial line. In small vessels, the surface of the liquid

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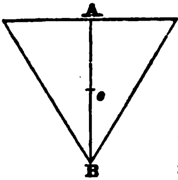

What is the position of this point in a vessel whose sides are parallelograms? What in a triangular vessel placed on its base? What when placed on its apex? 248. What is said of the level surface of a liquid? What does a perfectly level surface on the earth mean?

when at rest, is a perfectly horizontal plane, being in perfect equilibrium.

The sphericity of the earth is illustrated by the fact, that the masts of a vessel at sea are seen long before its hull is visible, whereas, were the surface of the water a perfect plane, the larger object would first become visible.

249. **Many liquids in the same vessel.**—If, instead of a single liquid in a vessel, we have a number, having different specific gravities, we shall find that the relative position in which they will come to rest, will be in the inverse ratio of their specific gravity.

Thus, if mercury, water and oil, are placed in a vessel, and after shaking them well together, they are allowed to rest, in a little time it will be found, that there are three layers; the mercury, being the heaviest, lies at the bottom; the water, lighter than the mercury, forms a layer immediately above; the third layer consists of oil, it being less dense than either of the other liquids.

250. **Equilibrium of a liquid in communicating vessels.**—If two or more vessels communicate with each other, the liquids in both or all the vessels stand at the same level. This law rests upon the fact, that the pressure of liquids at equal depths, is equal in all directions. If the fluid stands at a higher level in one vessel than the other, the particles of the former exert a greater lateral pressure on the channel of communication than the other can; these particles are, therefore, continually pushed upwards, until they exert an equal and opposite pressure, which obtains when the columns are at an equal height. The effect is the same, whatever may be the size and number of the vessels. Fig. 157 represents a number of vessels of different shapes and capacities, connected with a common reservoir; if we pour water into one of them, it will rise to the same height in the other vessels. The only circumstance af-

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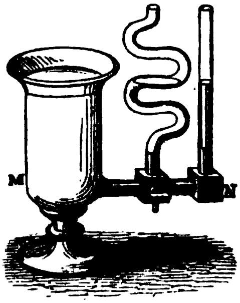

What is said of the sphericity of the earth? 249. What is the result when liquids of different densities are placed in the same vessel? Mention the illustration. 250. What is said of the equilibrium of liquids in communicating vessels? Describe the figure.

fecting this law would be capillarity, which, if certain of the tubes were very small, would cause the liquid to rise in them to a higher point than in the others.

Practical advantage is made of a knowledge of this law in the construction of aqueducts, or closed pipes, to supply towns and cities with water. The aqueduct often passes over very uneven surfaces for great distances, and the water is distributed to the houses by smaller pipes, branching from the greater ones. So long as the distributing pipes do not rise above the level of the fountain head, the water will continue to flow.

251. **Artesian wells.**—Water spouts from artesian wells for the same reason that liquids, in communicating vessels, tend to assume the same level, and streams flow toward the ocean. The crust of the earth consists often of various beds or strata, some permeable to water, like the sandstones, while others are impervious. Fig. 158 represents a portion of the earth containing two impermeable strata, *C C*, *B B*, and one pervious stratum, *A A*, between them. Supposing the latter to be in communication with more elevated lands, from which water filters in, then we should have a natural basin, from which the water could not escape, because of the impermeable strata above and below. If the upper strata are pierced by an artesian well, *F G*, the water, tending always to place itself in equilibrium, would rush up to a height towards the level line *H D*, and owing to friction, would, perhaps, reach the intermediate level *K*. Several very deep wells of this sort have been sunk in the salt regions of Virginia and Ohio. The famous well of Grenelle, in Paris, is 1806 feet deep, and the

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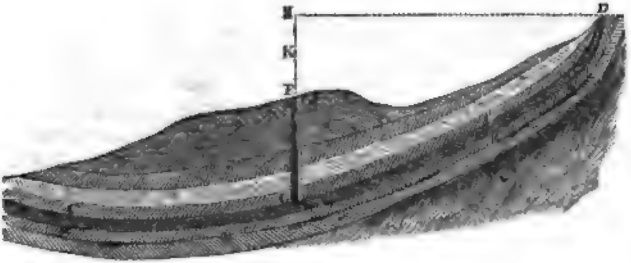

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251. Describe artesian wells. What is said of that at Grenelle?

water rises 112 feet above the surface, having a temperature of 83°·75 F., (the annual mean temperature of Paris being 53° F.) Over six hundred gallons are discharged each minute from this wonderful fountain, and without variation in quantity.

252. Equilibrium of liquids of different densities in communicating vessels.—When two liquids of different densities are placed in communicating vessels, their surfaces will not rest at the same point or level; *for in communicating vessels, the heights of the liquid columns are in the inverse ratio of the densities of the liquids.*

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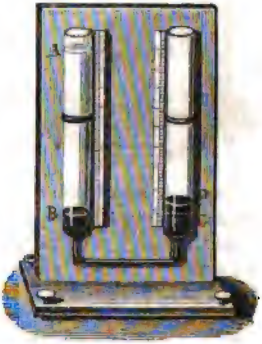

If mercury is first poured into the lower part of the apparatus, fig. 159, and the tube *A B* is then filled with water, this last will exert a pressure on the mercury, causing it to be depressed in *A B*, and rise in the other tube. Measuring the height of the columns of mercury *C D*, and water, *AB*, which are in equilibrium, they will be found to be as 1 to 13·59. These numbers represent the densities of water and mercury.

253. Hydrostatic paradox.—This term is applied to a practical illustration of the law of equality of pressures, and in proof of the seemingly paradoxical proposition, that a quantity of fluid, however small, may be made to counterbalance another, however large. We have seen (§ 237) that the pressure exerted on one of the pistons, fig. 146, would be felt equally on the rest, however great their number. If the pressure, instead of being communicated by a weight, was induced by a column of fluid acting upon a bellows, we should have the ordinary form of illustrating the hydrostatic paradox. The hydrostatic bellows, fig. 160, consists of two boards, *B C*, and *C D*, connected with leather or India-rubber cloth, in such a manner that the upper board can rise and fall, like the common air bellows. The tube *F E* communicates with the interior of the apparatus. Supposing the tube to have a cross section of one square inch, and

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252. What is said of the equilibrium of liquids of different densities in communicating vessels? 253. What is the hydrostatic paradox? Describe the hydrostatic bellows.

the top of the bellows to have a surface of 100 square inches, a pound of water in the tube would lift 100 pounds on the bellows, the weight of the water acting with a pressure equal to itself, (1 lb.,) on each square inch of the surface. The pressure is caused by the height of the column of water; for if we use a smaller tube, for the same bulk of fluid, the height of the column of water will be greater, and will raise a greater weight; if the tube be larger, the column will not be so high, and will not raise so large a weight.

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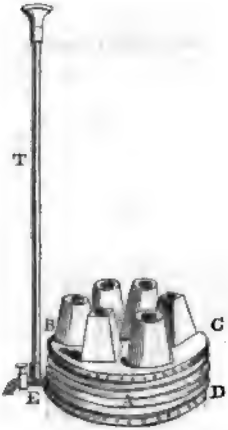

Another example, showing that a small quantity of water, through the medium of extended fluid surface, may produce a pressure of hundreds or thousands of pounds, is a cask filled with water, and which has a small tube screwed tightly in its top. A small quantity of water placed in the tube, will burst the cask; for, let us suppose the tube to have an area of a thirtieth of an inch, and to contain, when filled, half a pound of water, then the pressure exerted on each square foot would be more than 2000 lbs., a pressure greater than an ordinary cask can sustain.

254. **Hydrostatic press.**—The hydrostatic press acts upon the principle just explained; and if compared to the hydrostatic bellows, employs a strong forcing-pump, instead of the lofty tube, and a barrel and piston, instead of the leather and boards.

The main parts of this machine, fig. 161, consist of a small forcing-pump *A*, in which is a piston worked by a lever. This pump communicates with a large and strong cylindrical reservoir, B, by a tube indicated by the dotted lines in the figure. In this cylinder a water-tight piston moves, bearing at its upper end a flat metallic plate, between which and the top of the frame, *D*, the substance, *M*, to be compressed, is placed.

The cylinders are filled by means of the curved tube *H*, one end of which rests in a vessel containing water, or oil, the other terminates in the barrel *A*, and has a valve at its end

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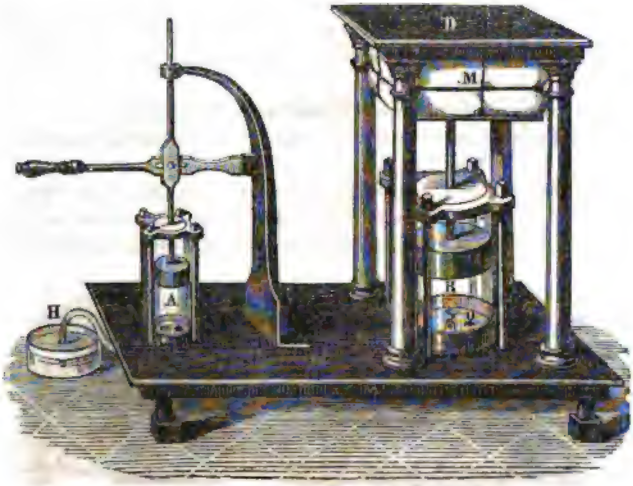
What is the experiment of the cask and tube? 254. Describe the hydrostatic press. How are the cylinders filled with water?

opening upwards. This valve opens when the piston is raised, thus drawing in water, and closes when the piston descends.

161



By working the piston, the barrels *A* and *B* are completely filled with water. The orifice *O*, is in connection with a stop-cock, by which the water can be drawn off, when we wish to reduce the pressure.

The pressure exerted on the water in *A*, by depressing the piston, is transmitted with equal force throughout the entire mass of the fluid. The surface of the water in *A*, therefore, presses up the piston above it, with a force proportioned to its area.

If the cylinder *B* has an area of 200 square inches, and the small cylinder an area of half a square inch, the pressure of the water on the piston above *B*, will be 400 times that applied at the lever. But let the arms of the lever be to each other as one to fifty, then when a force of fifty pounds is applied at the long arm, the piston will descend with a force of 2500 pounds, (50 × 50 = 2500,) and there will be exerted, theoretically, a force of 1,000,000 pounds upon the piston in *B*, (50 × 50 × 400 = 1,000,000,) or,

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How is the pump set in operation? What is the result of a great difference in the area of the pistons? How does the length of the arms of the lever affect the result?

deducting one-fourth for the loss occasioned by the different impediments to motion, a man would still be able to exert a force of 750,000 pounds. The hydraulic press is of extensive use in the industrial arts. It is employed for compressing cloth, paper, hay, and gun-powder, candles, vermicelli, and numerous other articles, to which the proper form or condition is imparted by severe pressure.

The tubes of the famous Britannia tubular bridge over the straits of Menai, were raised by means of a powerful hydraulic press.

255. **The water level.**—The water level, fig. 162, is an application of the law of the equilibrium of liquids in communicating vessels; it may consist of a metallic tube, bent upon its extremities, to each of which is adapted a vertical glass tube; this is mounted on a tripod. Water is poured into *E*, until the liquid is elevated in the tubes of glass. The equilibrium being established, the level of the water in the two tubes is the same; that is, the surfaces of the liquid in *D* and *E*, are on the same horizontal plane. By this instrument we can determine whether one point is more elevated than another, as *A* and *B*. By placing a sight-board at *A*, the observer, directing his eye along *D E*, immediately above the liquid, has the sight-board placed higher or lower by an assistant, until its centre is on the same horizontal line with *D* and *E*; measuring then the height *A M*, and subtracting it from the height of *D E*, above *B*, we find how much higher the point *A* is than *B*.

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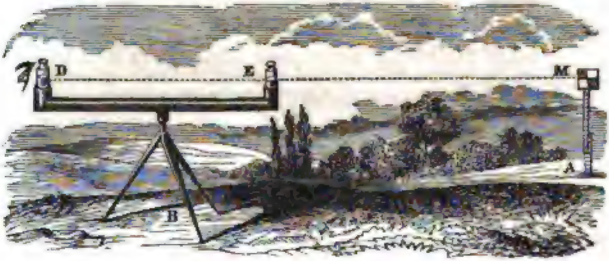

256. **The spirit level,** is a more accurate instrument than the above. It consists, fig. 163, of a tube, *A B*, sheathed in brass,

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How much force can a man thus easily exert? 255. Describe the water level. How are determinations made with it?

C D, slightly curved, and filled with alcohol, except a small space, *M*, occupied by a bubble of air. This always rises, to occupy the more elevated part. When the instrument is placed horizontally, the bubble remains in the centre, at a fixed mark, but when it is inclined, the bubble ascends.

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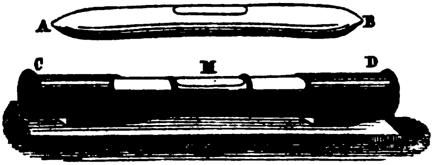

257. **Archimedes' principle.**—When solids are immersed in fluids, they displace a quantity of the latter, equal to their own bulk; a legitimate consequence of their own impenetrability. When a body is plunged in a fluid, its surfaces support the pressure of those particles it touches. Let a cube, fig. 164, be immersed, with two of its faces horizontal. The vertical faces being opposite, and the pressures against them being in contrary directions, they neutralize each other. The upper horizontal face is pressed downwards by a column of water, whose base is this face, and whose height is *A D*, and the lower horizontal face is pressed upwards by a column with an equal base, and having a height *D B*. The cube must, therefore, be floated upwards, by a force which is the difference between these two pressures, that is, equal to the weight of a mass of water corresponding in size to the immersed body. Consequently this pressure, opposing itself to gravity, the weight of the body is proportionally diminished, and it follows, that a body plunged in a liquid loses a part of its weight, equal to the weight of the liquid displaced.

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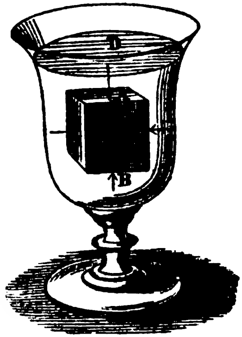

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256. Describe the spirit level. 257. What is the effect when solids are placed in water? What pressure is exerted on a cube sustained in water, as in the figure? What is the result of the action of these pressures?

This principle was discovered by Archimedes, about 230 years B. C., and is called after him, the *Theorem of Archimedes.* That it is correct, may be proved by means of the hydrostatic balance, fig. 165, from one of the arms of which is hung a hollow cylinder,

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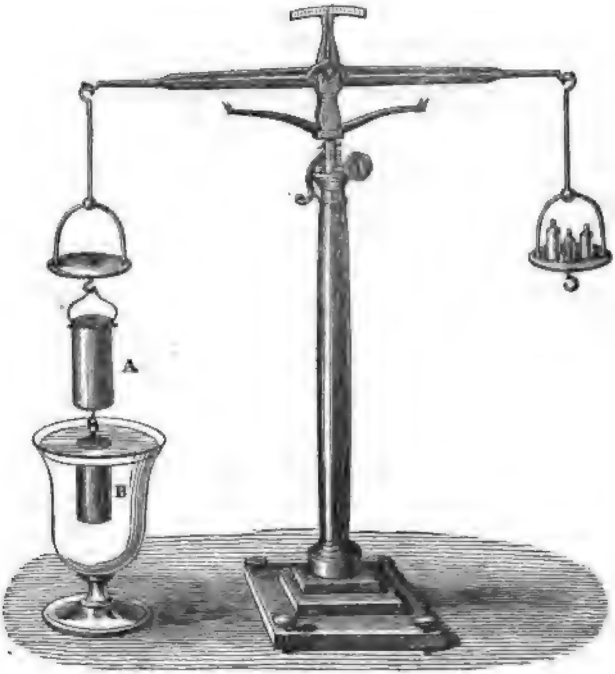

or bucket, *A*, having a cylindrical mass of copper, *B*, exactly fitting into it, and hanging from it by means of a fine wire. Having exactly counterpoised the beam by weights on the other arm, fill up the glass vessel with water, until the cylinder *B* is wholly immersed. The cylinder will then appear to have lost weight, the other arm going down. If the bucket *A*, is now exactly filled with water, the equilibrium will be restored ; proving that the immersed body has lost in weight equal to its own bulk of water.

Who was this principle discovered by? Describe the action of the hydrostatic balance.

258. **Equilibrium of floating bodies.**—Accepting the Theorem of Archimedes, agreeably to the last section, it follows, that if the immersed solid be of the same weight as the displaced fluid, the former will remain at rest in the fluid, in any position in which it may be placed, the upward pressure exerted upon the solid being equal to its own weight. If the solid is more dense than the fluid, its weight being greater than the upward pressure, the body will sink; while if the immersed body is less dense than the fluid, it will rise until it has displaced a volume of water equal to its own weight; that is, the body *floats*. For this reason, cork, wood, wax and other light bodies, placed in water, support themselves on its surface. In order that floating bodies may take a state of stable equilibrium, it is necessary, 1st. That they displace a weight of liquid equal to their own bulk. 2d. That their centre of gravity be below the centre of pressure, and in the same vertical. We may, however, still have stable equilibrium, when the centre of pressure is below the centre of gravity, but then it must be below a certain point called the *metacenter*, which can be determined by calculation. (In a slightly rolling, floating body, the point of intersection of the vertical, through the centre of gravity when at rest, is called the *metacenter.*) The knowledge of these points is of great value in the loading of a vessel; if the metacenter coincides with the centre of gravity, the equilibrium is stable in any position of the ship. Fishes are in a state of equilibrium when immersed in their own element, and in order to preserve this state at different depths, they have an air bladder, by contracting or expanding which, their bodies acquire the same density as that of the water in which they are.

259. **Cartesian devil.**—The hydrostatic toy, known as the cartesian devil or *ludeon*, exhibits the principle just stated. It consists of a small glass or enamel figure, fig. 166, at whose head is fixed a bulb of glass, *O*, having a small hole in its lower part, and filled with water to such an extent, that when placed in the cylinder of water as represented, it will remain in any position. Over the vessel's mouth is tightly fixed a piece of caoutchouc. If

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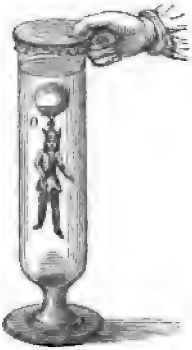
258. What is said of a solid immersed in a liquid, when it is of the same density as the displaced fluid? When the body is of greater density? What two conditions are necessary that floating bodies take a state of equilibrium? What is the metacenter? What is said of the advantages of a knowledge of these points? What is said of fishes? 259. Describe the cartesian devil.

the caoutchouc be pressed upon, while the figure is near the surface of the water, the air below is compressed, and this pressure will be conveyed through the water to the air contained in *O*; this will be compressed into a smaller bulk, and sufficient water will enter *O* to render the apparatus heavier than water, when it will fall. On removing the pressure, the air expands in *O*, and expels the water which was previously forced into it, and the apparatus rises. By a contrivance similar to this, the beautiful nautilus shell rises, to float upon the surface of the sea, or sinks again at pleasure, by a voluntary contraction or expansion of an internal cavity.

166



260. **Density.**—Different bodies, with the same volume, have different weights, owing to their containing unequal quantities of matter. This quality of bodies is called their density, or specific weight, and signifies the relation of the weight to the volume. The determination of density of a solid or liquid body, consists in ascertaining its weight, and also that of an equal volume of water, and in dividing the first weight by the second. Three methods are resorted to for determining the specific gravity of solids and liquids : *a*, by the balance, *b*, by the hydrometer, and *c*, by the flask.

261. **Specific gravity of solids heavier than water.**—The solid (heavier than water) whose weight is to be ascertained, being attached by means of a silk thread to the arm of a balance, and accurately weighed, will, upon immersion in water as in fig. 167, lose weight. This loss is equal (according to the principle of Archimedes) to the weight of a volume of water equal to that of the immersed body. Subtracting the weight of the substance in water from its weight in air, and dividing the latter by the difference, the product will be the specific gravity required.

Example. A piece of iron weighed in air, 460 grains, in water, 401·16 grs. Then 460—401·16 — 58·84 grs., which equals the weight

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Why does pressure on the India-rubber cause the figure to sink? Why does it rise? 260. What is the density a body? What does it signify? How are densities determined? 261. Describe the method for the determination of the density of a substance by means of the balance. State the example given.

of a volume of water equal to the iron, and 460 ÷ 58·84 = 7·8 = specific gravity of the iron.

262. **Specific gravity of solids lighter than water.**—If the body be lighter than water, it must be attached to some solid (whose weight in air and water is known) sufficiently dense to sink it in water. The compound mass is weighed first in air, and then in water, and the loss determined, the weight lost by weighing the heavy body alone in water being known, the weight of the light body in air, divided by the difference between these losses, gives the specific gravity.

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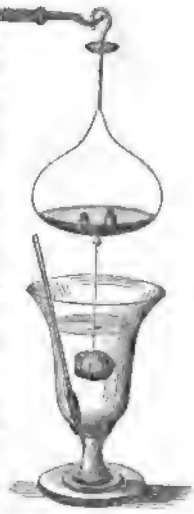

Example. A substance weighed in air, 600 grs., attached to a piece of copper, it weighed 2647 grs., in water 2020 grs., suffering a loss of 627 grs. The copper itself loses, when weighed in water 230 grs., 627—230=397, then 397 ÷ 604 = ·660 the specific gravity of the substance.

263. **Specific gravity of solids soluble in water.**—To determine the specific gravity of a solid soluble in water, we must weigh it while immersed in a fluid, in which it is not soluble, as oil of turpentine, alcohol, &c., its specific gravity, compared with that of the liquid being ascertained. To determine its density, compared with that of water, we have now only to multiply the specific gravity, thus found, by that of the fluid employed.

Example. A substance soluble in water was weighed in oil, and its specific gravity, compared with the oil, was 2·6, the specific gravity of the oil was ·87; then 2·6 × ·87 = 2·262 the specific gravity of the substance.

264. **Nicholson's areometer.**—This instrument, used for determining the density of solids, consists of a hollow cylinder of metal or of glass, *B*, fig. 168, having attached to its lower end

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262. How is the specific gravity of a solid lighter than water determined? State the example given. 263. How is the specific gravity of a solid soluble in water determined? State the example given.

a cone, *C*, loaded with lead, which causes the apparatus always to assume an upright position when placed in water. The upper part of the cylinder is terminated by a rod, on the end of which is a small cup, *A*, for holding weights. The whole apparatus must have a less specific gravity than water, so that a certain weight, as *X*, must be put in the cup, to sink the areometer to the water mark *O*. If we wish to determine the specific gravity of a body, (whose weight must be less than *X*,) we place the body in the cup *A*, and add weights till *O* is brought to the level of the water. The weight of *X* (the counterpoise) minus the weights last added, will be the weight of the body in air. It is now taken from *A*, and placed in *C*; it will there weigh as much less as the weight lost in water. We have now the data for determining the specific gravity of the solid. For example: if the counterpoise weighed 250 grs., and the mass of lead whose weight we wish to ascertain, requires 50 grs. to be added in order to bring it to the point *O*, then (250—50) 200 is the weight of the lead in air; placing now the mass on *C*, we should find that it would require the addition of 17·47 grs. on *A*, in order to counterbalance it; consequently the specific gravity is 11·45. (for $200 + 17{\cdot}47 = 11{\cdot}45$.) If the substance is lighter than water, we confine it under a little cage of iron wire placed on *C*, which prevents its rising.

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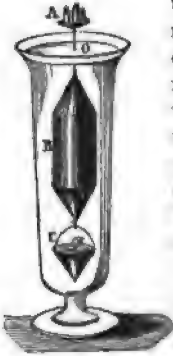

265. **Specific gravity bottles** are made of various forms and sizes, according to the particular object to which they are to be applied. The more common variety consists of a small light flask, (holding from 100 to 1000 grains,) with an accurately fitting stopper. There is often a small hole through the stopper, to allow the escape of any excess of liquid which may have been placed in the flask during filling.

A better form is seen in fig. 169, in which the stopper is hollow, and fits the flask so perfectly, that any liquid may be easily removed from the joint. Fig. 170 represents a form of specific gravity flask, which has advantages over most others. The flask is filled to a point *A* on the stem, the interior upper part wiped perfectly clean, and the stopper then inserted. If the liquid ex-

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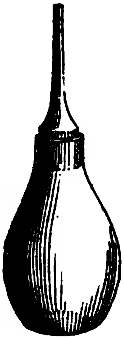
264. What is Nicholson's areometer? How is the specific gravity of a solid determined by this instrument? Give the example. 265. Describe the ordinary specific gravity flask. Mention other forms.

pands, it will rise in the tube, but cannot overflow and soil the exterior, as would be the case were other bottles used. In this form there is no danger of loss from evaporation. In many specific gravity bottles, a small thermometer is placed in the stopper, that the temperature of the liquid during the operation may be noted.

169



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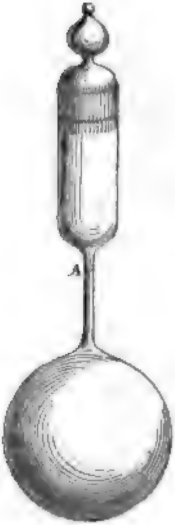

266. **Method with a flask.**—We use this method only for determining the specific gravity of solids in powder. A small bottle or flask with an accurately ground stopper is used. Having carefully filled the flask with water and dried it, we place it on the balance, together with the powder, whose specific gravity we wish to determine, and whose weight in air we know, after having counterbalanced it, we take the flask from the pan and throw in the powder, and then replace the stopper; a portion of the water is displaced by the powder; after drying the flask, we place it upon the pan and counter-balance. The number of grains added, represents the weight of a volume of water equal to that of the powder. The calculations are made in the same manner as in the other cases.

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266. How is the specific gravity of a substance in powder determined? 267. How is the specific gravity of a liquid determined by the balance?

267. **Specific gravity of liquids by the balance.**—To one arm of the balance, we attach, by means of a wire, a solid (as platinum,) on which the liquid whose specific gravity we wish, has no action; then, after weighing the platinum in air, we weigh it in water, and then in the given liquid, as oil, we observe the loss of weight the mass undergoes in these two liquids; those two numbers (the losses) represent the weight of equal volumes of water and the unknown liquid.

Example. The platinum weighs 275 grs. in air, in water, 262·5, losing 12·5 grs.; in oil, 253·75 grs., losing 11·25 grs.; then 11·25 ÷ 12·5 = ·9, specific gravity of the oil.

268. **Areometers.**—These instruments generally consist of a glass tube, terminated by a globe or long bulb, loaded with mercury or shot, fig. 171, so that they may assume a perpendicular position when placed in liquids. Upon or within the tube is a properly graduated scale, which allows of the determination of the density of the body by the greater or less depth it sinks in the liquid. Hydrometers for liquids lighter than water, sink to such a depth, if immersed in pure water, that the glass tube with the scale stands above the surface, those for liquids heavier than water, sink in that fluid to the very top of the scale. In both species, the water line is marked with 0° or 1, and the figures on the scale give the specific gravity corresponding to the depth of the immersion. Very often the figures on the scale, (and these are much the more convenient,) indicate at once the specific gravity. More often, however, the hydrometers are graduated in an arbitrary manner. Besides the areometers by which the specific gravity of any fluid may be determined, others are made for particular liquids. In which case, the scale is so graduated as to express the component parts per cent., by weight or volume. Such are called per cent. areometers or hydrometers, and are named after the liquid they are used for testing, as acid hydrometers, beer hydrometers, wine hydrometers, &c. Baumés' hydrometers are very

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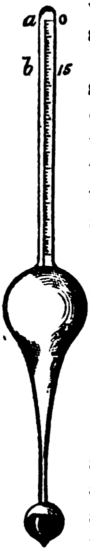

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268. What are areometers? What is said of hydrometers for liquids lighter than water? What of those for liquids heavier than water?

much used, being constructed for fluids both heavier and lighter than water. The one for the more dense fluids, sinks in pure water to the zero point of its scale; this is its highest point. The lowest point on the scale is 15°, to which it descends when immersed in a solution of fifteen parts of common salt, in eighty-five of water. Fifteen degrees are marked between these two extreme points. The one for fluids lighter than water, has its zero at the point to which it sinks in a mixture of ten parts of common salt, and ninety of water, and ten degrees where it stands in pure water. The space between these two points is divided into ten degrees. In both these hydrometers, the scale of equal divisions is extended throughout the length of the tube.

269. **By the specific gravity bottle.**—In order to determine the specific gravity of a liquid, use is made of a small flask or bottle. The weight of the bottle being known, it is first filled with water and weighed, afterwards with the liquid, whose specific gravity is desired, and again weighed; we have now the weights of equal volumes of water and of the second liquid, from which we deduce the specific gravity.

Example. Supposing the bottle held 852 grains water, and 784 grains of oil, the specific gravity of the oil is ·921, for $784 \div 852 =$ ·921. Very often the bottle is made to hold just 1000 grains of water, then upon determining the number of grains of the fluid of unknown density it holds, we have at once its specific gravity.

What is said of the zero, and the scales? What is said of per cent. areometers? Describe Baumé's hydrometer for liquids lighter than water. Those for liquids heavier than water. 269. How is the specific gravity flask used to determine the density of a liquid?

HYDRAULICS.

270. **Hydraulics,** (from *hudor*, water, and *aulos*, a pipe,) is that part of hydro-dynamics which treats of the art of conducting and elevating fluids, especially water, and the construction of all kinds of instruments and machines for moving them, or to be moved by them.

271. **Pressure of fluids upon the containing vessel.**—When a vessel is filled with water or any other liquid, its sides are submitted to two pressures acting in contrary directions. The atmospheric pressure, acting from without inwards, and the pressure of the column of fluid acting outwards against the sides. If a vessel so circumstanced has one of its sides pierced, and the pressure from within outwards is stronger than the external pressure, the liquid will flow out; while if the external pressure is the stronger, the fluid will not escape. This may be shown by filling a glass vessel, as a wine glass, with water, placing a piece of paper over its top, and then carefully inverting it. Holding it in this position, the fluid will not escape, the external (atmospheric) pressure against the paper, being greater than the weight of the column of water pressing downwards. The mass of liquid escaping from an orifice in a vessel, is called a *vein.*

272. **Appearance of the surface during a discharge.**—A vessel containing liquid, discharging itself by means of an orifice, does not always preserve a horizontal surface. When the vein issues

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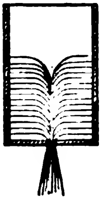

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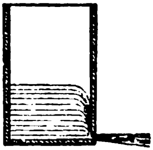

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270. What is hydraulics? 271. What is said of the pressures upon a vessel filled with liquid? How may this be shown? What is a vein? 272. What is the appearance of the surface of a vessel discharging liquid from an orifice in its lower part or in its side? What do the movements depend upon?

from an orifice in the bottom of a vessel, and the level of the liquid is near the orifice, the liquid forms a funnel-pipe, fig. 172; if the liquid had a rotary movement, the funnel is formed sooner. If the orifice is at the side of the vessel, there is a depression of the surface upon that side, above the orifice, fig. 173. These movements depend upon the form of the vessel, the height of the liquid in it, and the dimensions and form of the orifice.

273. **Theorem of Torricelli.**—When a liquid escapes from an orifice in a vessel, owing to the excess of the internal pressure, the volume which escapes depends on the section of the orifice, and the velocity with which the liquid molecules move at the moment of their escape from it.

This velocity depends upon the density of the liquid, the excess of pressure at the opening, and the friction of the liquid, both at the opening and against the walls. When the aperture is made in a very thin wall of a large vessel, so as to remove, as much as possible, the causes tending to modify the motion of the escaping fluid, the laws of the escape are comprised in the following theorem, discovered by Torricelli, in 1643, as a consequence of the law of the fall of bodies discovered by Galileo. *Liquid molecules, flowing from an orifice, have the same velocity as if they fell freely in vacuo, from a height equal to the vertical distance from the surface to the centre of the orifice.*

274. **Deductions from the Torricellian Theorem.**—1.—*The velocity depends on the depth of the orifice from the surface, and is independent of the density of the liquid.* Water and mercury in vacuo would fall from the same height in the same time; and so escaping from an orifice at the same depth, below the surface, would pass out with equal velocity; but mercury, being 13·5 times as heavy as water, the pressure exerted at the aperture of a vessel filled with mercury, will be 13·5 times as great as the pressure exerted at the aperture of a vessel filled with water.

2.—*The velocity of liquids is as the square roots of the depths of the orifices below the surfaces of the liquids.*

Thus stating the velocity of a liquid escaping from an orifice one foot below the surface, to be *one;* from a similar orifice four feet

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273. What does the volume of the liquid escaping from an orifice depend upon? Upon what does its velocity depend? State the Theorem of Torricelli. 274. What is the first deduction drawn from Torricelli's theorem? Give the illustration of water and mercury. What is the 2d deduction? Give illustrations of this deduction.

below the surface, it will be *two*, and at nine feet *three*, at sixteen feet *four*, and so on.

275. **Theoretical and actual flow.**—The actual flow from an orifice, is the volume of liquid which escapes from it in a given time. The theoretical flow, is a volume equal to that of a cylinder which has for its base the orifice, and for its height tho velocity, furnished by the theorem of Torricelli. That is, the theoretical flow is the product of the area of the orifice multiplied by the theoretical velocity. It is observed that the vein escaping from an orifice, contracts quite rapidly, so that its diameter is soon only about two-thirds of the diameter of the orifice. If there was no contraction of the vein after leaving the orifice, and its velocity was the theoretical velocity, the actual flow would be the same as that indicated by theory. But its section is much less than at the orifice, and its velocity is not so great as the theoretical velocity, so that the actual flow is much less than the theoretical flow; and in order to reduce this to the first, it is necessary to multiply it by a fraction which is named "the co-efficient of contraction."

From comparative experiments made by a great number of observers, it is learned that the actual flow is only about two-thirds of the theoretical flow.

276. **Means for obtaining a constant discharge.**—In order to verify many of the laws of hydraulics in an accurate manner, it is necessary to maintain a constant pressure on the escaping liquid, thereby obtaining a constant velocity at the orifice. This may be done in various ways, as by allowing the water to flow into the reservoir in a little larger quantity than can escape from the orifice; the excess being discharged through a tube or orifice at the upper edge of the reservoir. Also by means of the syphon, an instrument which will be hereafter described.

277. **Constitution of veins.**—The form and constitution of liquid veins have been studied by Savart.

He observed, 1st, that the fluid issuing vertically from an orifice made in a plane, and thin horizontal wall, is always composed of two distinct parts, fig. 174, the portion nearest the ori-

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275. What is meant by the actual flow from an orifice? What is the theoretical flow? What is meant by the co-efficient of contraction? What proportion does the actual flow bear to the theoretical flow? 276. What means are used for obtaining a constant discharge of liquid from a vessel?

fice is calm and transparent, like a rod of glass, gradually decreasing in diameter. The second, on the contrary, is always agitated, and takes an irregular form, in which are regularly distributed elongated swellings, called *ventres*, whose maximum diameter is greater than that of the orifice.

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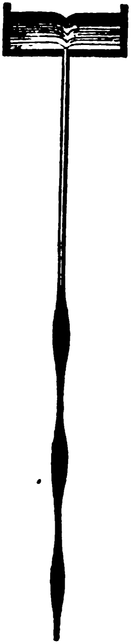

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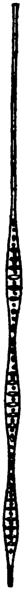

2.—In the second part of the vein, the liquid is not continuous; for if we employ an opaque liquid, as mercury, we can see through the vein, fig. 175. The apparent continuity in a vein of water, is owing to the fact, that the globules which constitute it succeed each other at a distance inappreciable to the eye. Savart found that the *ventres* are formed of disseminated globules, elongated in the tranverse direction of the vein, and that the contractions or knots are formed of globules, elongated in the longitudinal way, fig. 175. He also found that the limpid part of the vein is formed of annular swellings which originate very near the orifice, propagating themselves at unequal intervals to the troubled part, where they separate, of the same form at the instant of their separation, but changing periodically.

3.—The annular swellings arise from a periodical succession of pulsations near the orifice, which must be produced by very small oscillations of the entire mass of the liquid, so that the velocity of the flow is periodically variable. The number of these pulsations is in direct ratio with the swiftness of the flow, and in inverse ratio with the diameter of the orifice; they are sufficiently rapid and regular to give rise to a well characterized sound. The air has no influence on the dimensions of the veins, or on the sound they produce.

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277. What two distinct parts have been observed by Savart in a liquid vein? What is said of the second part of a liquid vein? What is said of the constitution of these ventres? What is the limpid part of the vein formed of? What is the course of these annular swellings? What is said of the number of pulsations? What is the effect of the sounding of a musical instrument near the veins?

4.—If we produce, with a musical instrument at some distance, the same or a similar sound, the vein undergoes a remarkable modification; the swellings and knots assume more regularity, and usurp the transparent part, which almost entirely disappears, the flow of the liquid from the orifice remaining the same as at first.

5.—The constitution of veins thrown out in any direction is essentially the same; but the number of pulsations is diminished in proportion as the vein is thrown out more vertically upwards.

278. **Contraction of the vein.**—The vein, escaping from a circular orifice, preserves a circular section, but a varying diameter. Its diameter at first being equal to the orifice, is diminished rapidly, until, at a distance a little greater than its first diameter, the section of the vein is but about two-thirds that of the orifice. If the vein flows directly downwards, the decrease in size continues to the troubled part. If the jet issues horizontally, the decrease is scarcely noticeable; if it is directed upwards, at an angle of 25° to 45°, the vein preserves its own diameter; but if its angle surpasses 45°, its section increases to the troubled part.

By suspending solid particles in the water, we render the currents that are formed, visible. These solid particles direct themselves, in curved lines, towards and into the orifice, as a centre of attraction, fig. 176. The particles in immediate contact with the orifice, not moving so easily as those within, must cause contraction; so, also, we can see that gravity in accelerating the velocity, must cause continual decrease in the section of the jet.

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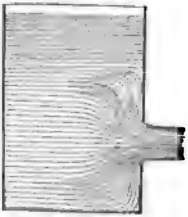

279. **Escape of liquids through short tubes.**—We often place in an orifice, to increase the flow, a short tube, (called an *adjutage*) either cylindrical or conical. If the vein pass through the tube without adhering to it, the flow is not modified; if the vein adhere, (the liquid wetting the interior walls,) the contracted part is dilated, and the flow increased. In the last case, and with a cylindrical ad-

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What influence has the direction of the vein upon its constitution? 278. What is said of the contraction of the vein? What is said of the contraction if the direction of the vein is directly downwards? What when issuing horizontally? How may these currents be seen? 279. What is said of the escape of liquids through short tubes?

jutage, its length not being more than four-times its diameter, the flow is augmented about one-third. Conical cones, converging towards the exterior of the reservoir, increase the flow still more than the preceding, the flow and velocity of the vein varying with the angle of convergence. Conical adjutages, diverging towards the exterior, give the greatest flow; they may give a flow 2—4 times as great as that which an orifice of the same diameter in a thin wall furnishes, and 1·46 times greater than the theoretical flow.

280. **Escape of liquids through long tubes.**—When a liquid passes through a long straight tube, the flow soon diminishes greatly in velocity, because of the friction which takes place between the liquid particles and the walls. It is again further diminished by the same cause, if there be any bends or curves in the tube. The discharge is very much less than it would be from an orifice in a thin wall, and therefore the tube is generally inclined; the liquid then passes down an inclined plane, or it is forced through by pressure, applied at the opposite end.

281. **Escape of liquids from capillary tubes.**—Fluids escaping from capillary tubes, (tubes having a fine or hair-like bore,) are subject to the following laws, (the tubes being of glass.)

1.—For the same tube the flow is proportioned to the pressure.

2.—With tubes having an equal pressure and length, the flow is proportional to the 4th power of their diameters.

3.—For the same pressure and the same diameter, the flow is in inverse ratio to their length.

4.—The flow increases with the temperature.

The inequalities in the flow of different liquids under the same circumstances does not seem to depend on their viscosity or their density; for alcohol flows slower, and oil of turpentine, or sugar solution, faster than water. So also nitrate of potash solution, flows faster than pure water, and serum flows less swiftly; alcohol added to serum retards its movement, while if nitrate of potash solution be added to the mixture, the serum recovers its usual velocity. These experiments made with glass tubes, were repeated on the bodies of animals recently killed, by injecting the various

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What is the amount of flow with a cylindrical adjutage? What is said of the effect of conical tubes? What form gives the greatest flow? How does the actual flow then compare with the theoretical flow? 280. What is said of the escape of liquids through long tubes? 281. What are the laws of the escape of liquids through capillary tubes?

fluids into the principal arteries. The results were found to accord, tending to prove that the circulation of blood and other fluids in the arteries and veins of living bodies, is subject to the same laws as the flow of liquids in capillary tubes of glass.

282. **Jets of water.**—As the velocity of a liquid escaping from an orifice is the same as that which a body acquires falling from a height equal to the distance from the level of the liquid to the orifice, a jet of water escaping from a horizontal opening, upwards, should rise to the level of the liquid in the reservoir. But this never quite takes place, (fig. 177,) because of—1st, the friction in the conducting tubes destroying the velocity—2d, the resistance of the air—3d, the returning water falling upon that which is rising. The height of the jet is increased by having the orifices very small, in comparison with the conducting tube; piercing them in a very thin wall, and inclining the jet a little, thus avoiding the effect of the returning water.

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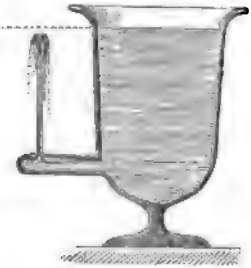

283. **Velocities of streams.**—The velocity of streams varies very much. The slower class of rivers have a velocity of less than three feet per second, and the more rapid, as much as six feet per second, which gives respectively about two and four miles per hour. The velocities vary in different parts of the same transverse section of a stream, for the air upon the surface of the water, as well also as the solid bottom of the stream, has a certain effect in retarding the current. The velocity is found to be greatest in the middle, where the water is deepest, fig. 178, somewhere in *m*, below the surface; then it decreases with the depth, towards the sides, being least at *a* and *b*.

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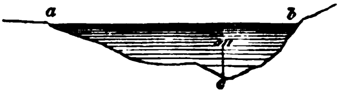

284. **Stream measurers.**—To measure the velocities of streams, various means are employed. The most simple is a glass bottle

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What is said of viscous liquids? What is said of serum? What is said of the circulation of blood. 282. What is said of jets of water? Why does not the jet rise to the theoretical height? How may the height be increased? 283. What is said of the velocities of streams? Where is the velocity greatest?

filled with water, sunk just below the level of the current, and provided at the cork with a small flag, that stands above the surface. Or a wheel may be used, furnished with float-boards, placed in the stream and immersed, so that the whole surface of the boards are covered with water. The friction in this case is very small, so that the wheel revolves with very nearly the velocity of the stream. By observing the number of revolutions of the wheel in a given time, we can ascertain the rapidity of the current. To ascertain the velocity at different depths, the simplest instrument is Pictot's tube: it consists of a tube bent nearly at right angles, terminated by a funnel-shaped mouth, the upper part of the tube, above water, is of glass. In order to observe with this instrument, it is placed in the direction of the stream, at the depth we wish to ascertain its velocity. If the water was still, the height within and without the tube would be equal, but if it is in motion, the water will rise in the tube to counterbalance the force with which the water is impelled, (the impulse of the stream,) the column of water in the tube rising higher as the velocity of the stream is greater.

285. **Water-wheels.**—The motive power of water is of extensive practical importance, from the number of machines driven by water-wheels.

The over-shot wheel.—Fig. 179 is used when the supply of water is moderate and variable. The water is delivered at the top of the wheel, which may move with the hands of a watch, as in the figure, or the reverse. It is furnished with buckets of such a shape as to retain as much of the water as possible, until they reach the lowest practicable point on the wheel, and none after that point. In this wheel the effect is produced both by impact, and by the weight of the water.

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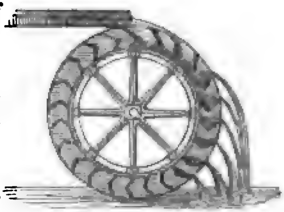

The under-shot wheel.—Fig. 180 receives its impulse at the bottom; it is furnished with float-boards instead of buckets. If they are placed at right angles to the rim of the wheel, they may turn either way. When the wheel is required to

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284. What are stream measurers? What is the most simple? Describe other forms of stream measurers? What is Pictot's tube? Describe its mode of action. 285. Describe the over-shot wheel. How is the effect produced in this wheel?

turn only in one direction, the float-boards are placed as in the figure, so as to represent an acute angle towards the current, the water acts then partly by its weight.

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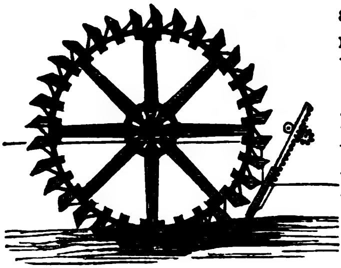

The breast wheel.—Fig. 181 is moved both by the weight and momentum of the water. It is furnished with buckets, formed to retain the water as long as possible. The breast-wheel is the form most generally adopted, as it allows of a larger diameter for a given fall than the overshot-wheel, with more economy of power than the undershot-wheel. According as the water is received above or below half-past nine, or half-past three on the watch, the wheel is called a high or low breast wheel.

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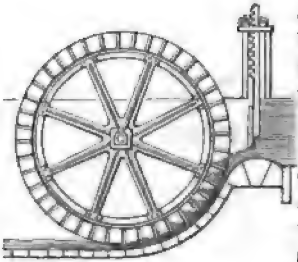

A more distinct idea of these different water wheels may, perhaps, be gained by illustration from the face of a watch. In the breast wheel, the water may be received, (according to the desired motion of the wheel,) between eight and eleven o'clock, or between one and four o'clock. In the over-shot wheel, the motion usually is the same in direction as the hands of the watch. The water is received as near the summit as possible, and the buckets are so shaped as to retain the water to the lowest practicable point in its descent, corresponding to about five on the face of the watch.

The turbine is a horizontal water-wheel, revolving entirely submerged, and is, of all forms of water-wheel, the most energetic and economical of power. The water descends in the vertical axis of the wheel, and is delivered through a great number of curved buckets, so arranged, that the escaping water is nearly a tangent to the diameter of the wheel. It runs in a stationary

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What is said of the under shot wheel? What is said of the float-boards in this wheel? What is said of the breast-wheel? Illustrate the operation of these wheels from the face of a watch. What is the turbine wheel?

case, also provided with cells, curved in the opposite direction, through and against which the escaping water acts. Over 80 parts in a hundred of the whole power are saved by this wheel.

Capillarity.

286. **Capillary phenomena.**—The laws of the equilibrium of liquids of which we have treated, do not obtain unless the vessels are of considerable diameter; when the vessels are very small, the laws of equilibrium are entirely different. For example: when we plunge a tube of very small diameter, open at both ends, in a liquid, if the tube becomes wet, the liquid is elevated within and upon the outside, and maintained at a height more considerable as the diameter of the tube is smaller, fig. 182. If the tube does not become wet, there will be a depression, greater as the tube is of smaller diameter, fig. 183.

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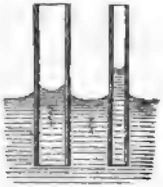

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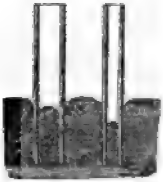

287. **Laws of the rise and fall of liquids in capillary tubes.**—It has been demonstrated by M. Gay Lussac, that the elevation and depression of liquids in capillary tubes is in accordance with the three following laws:—

1st.—*There is an elevation when the liquid wets the tube, and a depression when it does not.*

2d.—*The elevation and depression are in an inverse ratio to the diameters of the tubes when the diameters do not exceed* 2 *or* 3 *m. m.* (·07874, to ·11811 inches.)

3d.—*The elevation and depression vary with the nature of the liquid and the temperature, and is independent of the substance of the tubes and thickness of their walls.*

288. **Cause of capillarity.**—Since capillary phenomena take place as well in the atmosphere as in a vacuum, it is plain that the air does not influence their production, but that they are due to the

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286. What is said of the equilibrium of fluids in very small vessels? 287. What are the laws of the ascension and depression of liquids in capillary tubes? 288. What is the cause of capillarity?

molecular attraction of the liquid on itself, and on the substance of the solid body; actions which are manifested only at very small distances.

289. **Cause of the curve of liquid surfaces by the contact of solids.**—The form of the surface of a liquid in contact with a solid, depends upon the relation which exists between the attraction of the solid for the liquid, and the liquid particles for each other. Any liquid particle, as *m*, fig. 185, is submitted to three forces, viz: 1st, of gravity, which acts in the direction *m p*, 2d, the attraction of the liquid particles, acting in the direction *m F*, and 3d, the attraction of the solid acting in the direction *n m*; according to their intensities the resultants of these forces may take three directions.

If the attraction of the liquid particles is double that of the solid for the liquid, the surface of the liquid will be perpendicular to the resultant *m R*, fig. 184, and it will remain level. If the attraction of the liquid particles is less than double that of the solid for the liquid, the resultant will have the direction *m R*, fig. 185, and the surface will be concave; while if the attraction of the liquid particles is greater than double of the solid for the liquid, the resultant will be in the line *m R*, fig. 186, and the surface will be convex.

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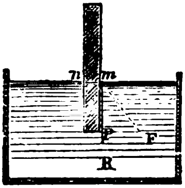

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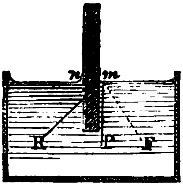

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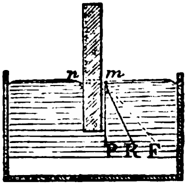

290. **Influence of the curve on capillary phenomena.**—The curved surfaces in capillary spaces are called, respectively, *concave* and *convex meniscuses;* the ascent or depression of liquids in such spaces, are owing to these forms. Let *a b c d*, fig. 187, represent a concave meniscus, the particles of which are sustained in equilibrium by the forces before mentioned; these par-

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289. Upon what does the form of the surface of a liquid in contact with a solid depend? What is the resultant when the attraction of the liquid particles is double that of the solid for the liquid? When the attraction of the liquid particles is less than double? When the attraction of the liquid particles is greater than double?
290. What are the curved surfaces in capillary spaces called?

ticles do not exercise any pressure on those below them, consequently no layer in the interior of the tube exerts a pressure equal to one without. But because of the condition of equilibrium in fluids, the liquid will be raised by molecular attraction, until the pressure exerted in the interior *d a n m*, is equal to the pressure exerted exteriorly, by any column *o p*, which has its base on the same layer.

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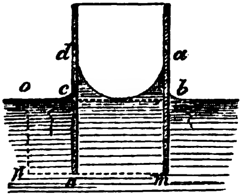

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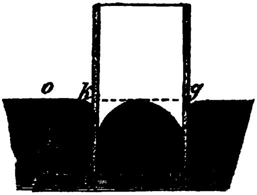

Where as in fig. 188, the meniscus is convex, the equilibrium still exists, for the liquid molecules, being repelled from the capillary walls, do not attract those below them, and therefore the pressure on any layer *n m*, in the interior of the tube, is less than if the space *g h i k* was filled, for the molecular forces are much more intense than gravity; therefore the liquid falls in the tube, until the pressure on the base *n m*, is the same as that on any point *q*, of the layer.

291. **Law of the elevation and depression of liquids in capillary tubes.**—It has been demonstrated by Laplace, that the attraction of the meniscus is equal to a constant co-efficient, depending on the nature of the liquid and that of the tube. In a cylindrical tube with a circular base, experience has demonstrated, that the concave surface is sensibly a hemisphere, with a radius equal to half the diameter of the tube. The attraction of the meniscus is, therefore, in inverse ratio with the radius, or the diameter of the tube, and in consequence, the liquid column will be raised by this force to a height which varies according to its intensity. The length of the liquid column contained in the tube is a little less than calculation (according to the above rule) would indicate, because of the weight of the meniscus, but this error is very small, less as the capillarity of the tube is less, the

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What is said of the action of the concave meniscus? What is said of the action of the convex meniscus? 291. To what is the attraction of the meniscus equal? What is the form of the concave surface in a cylindrical tube?

influence of the weight of the meniscus decreasing rapidly as the diameter of the bore diminishes. The height of the liquid in the tube is, therefore, never absolutely in inverse ratio to the diameter, but the law is nearly exact when we add to the height one-sixth of the diameter of the tube, which is the correction required for the weight of the meniscus.

Corrections for this error, being thus made, the law would be correct, had the meniscus an accurately spherical surface, but this does not obtain, but when the diameter is very small (2 or 3 *m. m.*, ·07874, or ·11811 inches) the surface in general ceases to be truly spherical, and the ascent or depression depends on the curve of the surface, which varies much more rapidly than the diameter of the tube.

292. **Depression of mercury in capillary tubes.**—The rapidity in which capillarity diminishes, in tubes of great diameter, is seen in the following table.

TABLE OF DEPRESSIONS OF MERCURY IN CAPILLARY TUBES.

Diameter of tube.	Depressions in m. m. according to Laplace.	According to Young.	According to Jaoby.	According to Cavendish.
20· m. m.	0·038	0·031	0·031	
15· “	0·137	0·111	0·118	0·131
10· “	0·445	0·402	0·406	0·406
8· “	0·712	0·669	0·673	0·820
6· “	1·171	1·139	1·134	1·377
5· “	1·534	1·510	1·513	1·735
4· “	2·068	2·063	2·066	2·187
3· “	2·918	2·986	2·988	3·054
2·5 “	3·566			
2· “	4·454	4·887	4·888	4·472

The numbers contained in the first column have been calculated by M. Bouvard, according to the formula of Laplace; those of the two last columns have been obtained directly by experiment.

293. **Ascent of liquids in capillary tubes.**—For all liquids, the ascent or depression in capillary tubes, decreases according to

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What is the relation between the attraction of the meniscus and the diameter of the tube? Why is the length of the column in a tube less than that indicated by theory? What is the correction required for the weight of the meniscus? Has the meniscus always an accurately spherical surface? 292. Mention some figures from the table showing the rapidity in which capillarity diminishes in tubes of great diameter. 293. What is said of the ascent of liquids in capillary tubes?

analogous laws. If the tubes are very small, the heights augmented with one-sixth of their diameter, are inversely as the diameters. If the tubes are very large, we may ascertain very accurately the heights to which liquids would rise by very complicated calculations, or we may obtain, approximately, their capillary effects, in supposing them proportional to the depression mercury undergoes in tubes of the same diameter. For the same tube, and for the same liquid, the capillarity depends much on the temperature, decreasing more rapidly than the density.

According to M. Gay Lussac, the elevation of water in a capillary tube of 1 m. m., (·03937 in.) is 30 m. m., (·11811 in.) and different liquids elevate themselves, in the same tubes, to heights, which are in the following relation.

Water,	100·
Saturated solution of chlorid of ammonium,	102·7
" " sulphate of potash,	95·7
" " " " copper,	84·
Nitric acid,	75·
Hydrochloric acid,	70·1
Alcohol,	40·8
Oil of lavender,	37·5

294. **Laws of the equilibrium of liquids between parallel or inclined laminae.**—Phenomena analogous to those presented in capillary tubes, may be observed when two laminae, plunged in a liquid, are brought near to each other. If the laminae are made wet, the liquid elevated between them, is terminated by a cylindrical surface; if not moistened, the liquid is depressed, and is terminated by a convex surface; and it is observed that

1st.—*A liquid is regularly elevated or depressed between two laminae, inversely as the interval which separates them.*

2d.—*That the height of the ascension or depression for a given interval, is half that which would take place in a tube having a diameter equal to that of the interval.*

When we plunge two inclined laminae (with their line of contact in a vertical position) in a liquid which wets them, a concave surface may be observed between them, fig. 189, the liquid rising toward the upper point of their line of contact. The

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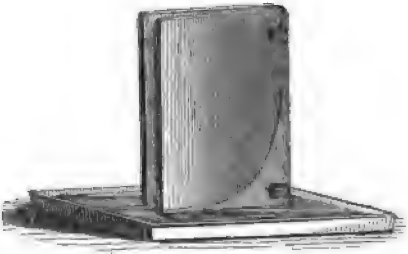
Mention the elevation of different liquids in tubes of 1 millemetre diameter. 294. What is said of the equilibrium of liquids between two laminae? What are the laws which have been observed of this phenomena? What is the form of the curve a liquid takes between two laminae?

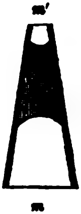
surface of the liquid takes the form of the curve known in geometry, under the name of the *equilateral hyperbole;* this curve is produced by capillarity.

189



295. **Movements of drops of liquid between laminae.**—When a drop of liquid is contained in a conical tube, or between two laminae having their lines of contact horizontal, the liquid, if it wets the tube or laminae, is terminated by two concave surfaces, fig. 190, and the liquid is precipitated towards the summit of the angle; because the radius of the curve being smaller at the point *m'*, than at *m*, the pressure at the point *m'* will be greater than at the point *m*. If the liquid does not wet the surrounding body, the drop terminating in a convex meniscus, fig. 191, elongates itself toward the summit of the angle, because the radius of the curve, being smaller at the point *m'*, than at the point *m*, the pressure at *m* will be greater than at *m'*.

190



296. **Attraction and repulsion of light floating bodies.**—The attraction and repulsion which we observe between light bodies floating on the surface of liquids, is due to capillarity. The floating bodies are drawn near to each other either when they are or are not moistened, and repelled if the liquid wets only one of them.

For, supposing we have two parallel vertical laminae at a capillary distance, plunged in a liquid which wets them, the exterior and interior surfaces of the same laminae, situated at the same height, and plunged in the same liquid, are

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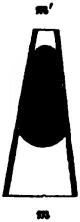

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295. What is said of a drop of liquid placed between two laminae, as in fig. 190, that it wets? What is the result when the drop of liquid does not wet the laminae? 296. What is said of the attraction and repulsion of light bodies floating on the surface of liquids?

pressed; and as all the points of the interior surfaces of the laminae which are not wetted by the liquid, are pressed from without internally, with a force as much greater as the points are more elevated, it is plain, that if the laminae are movable, they would be drawn towards one another. If the two laminae were not wetted by the liquid, then any two corresponding points on the two faces of the laminae, situated below the interior level of the liquid, are pressed equally, while a point that is wetted by the liquid only externally, experiences a pressure which, not being destroyed, would make the laminae, if movable, draw near each other.

Lastly, in that case, where one of the laminae was wetted and the other not, the interior liquid is depressed against one and elevated against the other, and by a reasoning similar to that already employed, we may see that the parts of the laminae which are covered on both sides by the liquid, are equally pressed from without and from within, but that in the upper part of the first, and the lower part of the second, the pressures are exerted from within outwards, and in consequence, the laminae must be repelled.

297. **Effects produced by capillarity.**—A needle covered with grease, placed lightly upon the water, floats, because, not being moistened by the liquid, there is produced a depression in which it is supported. So, many insects walk and skim on the surface of water without plunging in. Oil and other burning-fluids in lamps, and the melted tallow and wax of candles, are supplied to their flames by means of the capillarity of their wicks, so there is an absorption of liquids in wood, in sponge, in cloth, and in all bodies that possess sensible pores.

Endosmose.

298. **Endosmose.**—Closely allied to capillarity are the phenomena of endosmose, which have been very accurately studied, particularly by M. Dutrochet, who brought forward his researches, in the year 1827; and by Prof. Graham, more lately. When two liquids capable of mixing with each other, are separated by a membranous partition or wall, two currents become established, proceeding, one from within outwards, called *exosmose*, (from *ex*, outward,

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Describe the action when two laminae are wetted by the liquid in which they are placed. What is the action when the laminae are not wetted by the liquid? What is the action when one of the laminae is wetted and the other is not? 297. Mention some of the effects produced by capillarity? 298. What is said of endosmose, and who have been its chief investigators?

and *osmos*, impulsion,) and another in the contrary direction, called *endosmose*, (from *endon*, inward, and *osmos*.)

299. **Endosometer.**—The existence and rapidity of these currents is ascertained by the *endosometer*, an instrument which may be thus constructed. To a membranous pouch or bladder is fitted, hermetically, a glass tube as in fig. 192.

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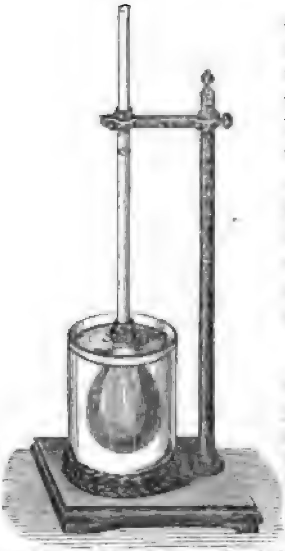

The jar or bladder, and part of the tube, is filled with a dense liquid, as a strong solution of gum or sugar, and placed in a tall cylindrical jar, which is then filled with distilled water, until it stands exactly at the level of the fluid in the tube. For very exact experiments, this level is constantly maintained by the addition to, or the removal of the water in the outer jar. After a time, gum will be found in the outer vessel, a current from without, inwards, also taking place.

If we wish to determine more accurately the actual as well as the comparative flow of different liquids, we may use an apparatus constructed as follows. Over the open mouth of a bell jar, of a few ounces' capacity, is placed a plate of perforated zinc, to support firmly a piece of fresh ox-bladder, which is securely tied over it. To the upper aperture is attached a graduated tube, open at both ends, the capacity of whose interior bears a certain definite relation, as $\frac{1}{10}$th, to that of the lower opening of the bell jar; so that a rise or fall in the tube as of 100 m. m. (3·937 in.) indicates the entrance or removal of a stratum of liquid, 1 m. m. (0·03937 in.) thickness over the whole surface.

300. **Necessary conditions.**—According to M. Dutrochet, in

What is the result when two liquids capable of mixing with each other are separated by a membranous partition? 299. What is the endosometer? How may it be constructed? Mention another form. How are endosometers set in operation? 300. What are the necessary conditions for producing endosmotic phenomena? 301. What is said of materials for septum? What is said of inorganic materials? What of chemical action?

order successfully to produce the phenomena of endosmose, it is necessary,

1st.—*That the liquids be susceptible of mixing.*

2d.—*That they are of different densities.*

3d.—*That the membrane or wall (septum) which separates them is permeable to one or both liquids.*

301. **Materials for septum.**—All thin animal and vegetable membranes, thin plates of burnt clay, slate, marble, pipe-clay, &c., produce endosmotic effects in a more or less notable degree. Of inorganic materials, those which contain most silicic acid are less permeable. A chemical action on the materials of the septum, invariably takes place, (excepting with alcohol and cane sugar solutions,) whether it is formed of bladder or of earthenware. Where the partition is not susceptible of being acted upon, the endosmotic action is very slight.

302. **Direction of the current.**—The endosmose current is in general directed towards the more dense liquid, but alcohol and ether are exceptions; they acting as denser liquids, although lighter than water; so also as acids are more or less diluted, there is endosmose towards the acid or towards the water. The excess in the quantity of the liquid which passes into the endosometer, is proportional to the surface of the membrane, and to the different heights to which the liquids mount in capillary spaces, the elevation taking place from that side of the liquid which has least capillary action.

303. **Organic solutions.**—Neutral organic substances, such as gum-arabic, urea and gelatine, produce but little endosmotic action. Of all vegetable substances, sugar solution; and albumen among animal bodies; are those which, with equal density, possess the greatest power of endosmose. The figures attached to the following substances, indicate the proportional height to which the liquids rose when the endosometer, being filled successively with solutions of them, of the same density, was placed in pure water: gelatine 3, gum 5, sugar 11, albumen 12.

304. **Inorganic solutions.**—Neutral salts do not possess any peculiar power of endosmose, but diffuse themselves with nearly

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302. What is generally the direction of the endosmose current? What is the excess of the quantity of liquid which passes into the endosometer proportional to? 303. What is said of neutral organic solutions? What vegetable and animal substances have the greatest power of endosmose? Mention the proportional height to which the liquids rose in the tube when the endosometer was filled with gelatine, gum, sugar and albumen.

the same rapidity as if no porous partition was used. Alkaline solutions greatly accelerate endosmose. This may be observed, even in solutions which contain but 1 part of the alkaline salt in 1000 of water. In moderately dilute solutions (containing not more than 2 per cent. of the salt) the action is most rapid.

305. **Theories of endosmose.**—Many theories have been proposed to account for these phenomena: such as that endosmose was due to an unequal viscosity of the two liquids; to currents of electricity passing in the direction of the endosmose; to the unequal permeability of the membrane for the two liquids, or, that the phenomenon was due to capillary action, joined to the affinity of the two liquids. Very probably endosmose depends on the same forces that produce capillarity, but obviously they are not the only forces which exert influence, for we find that heat, which always diminishes capillarity, augments the strength of the endosmose.

306. **Endosmose of gases.**—There is endosmose between gases, as between liquids; if we connect two vessels containing different gases, having a dry membrane between them, the gases will gradually mix, equal currents being established in both; but if the membrane is moist, unequal currents, (that, is endosmose,) are formed. So, a soap bubble placed in a jar of carbonic acid, will, in a little time, burst, owing to the increase of volume caused by endosmose.

307. **Absorption of gases.**—All bodies possessed of sensible pores have, in a more or less considerable degree, the property of absorbing gases. Box-wood charcoal possesses this property in the most remarkable degree, 1 volume of it absorbing 90 volumes ammonia, 81 volumes hydro-sulphuric acid, 32 volumes of carbonic acid, 9¼ volumes oxygen, &c. If the charcoal is moistened, its absorbing power is diminished one-half, which proves that this power is due to porosity, and in consequence to capillary action; other kinds of charcoal have less and very varying absorptive powers; those which are very porous and extremely com-

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304. What is said of neutral salts? What of alkaline solutions? What of moderately dilute solutions? 305. Mention some of the theories that have been proposed to account for endosmose phenomena. Upon what probably does endosmose depend? 306. What is said of the endosmose of gases? How may it be illustrated? 307. What is said of the absorptive powers of box-wood charcoal? What is the effect of moistening the charcoal? What is said of other charcoals and their porosity?

pact, possessing this property in a less degree than others. Porosity, however, although an essential condition of the absorption of gases, must be confined within certain limits.

308. **Phenomena of absorption in plants and animals.**—In Physiology we distinguish absorption from imbibition, applying the first term to those phenomena where there is a penetration of a substance (liquid or gaseous) in the tissues of a living being, while imbibition is the penetration of a gaseous substance into a porous body deprived of life, either organic or inorganic. In all vegetable life, absorption is taking place from all parts of the plant, but chiefly from the spongioles which terminate the roots, and from the leaves. These organs absorb water, carbonic acid, and ammonia, whose constituents are the necessary food of the plant. Capillarity only elevates the liquid in the lower part for the plant, it does not produce the upward current; the liquid, with the salts it contains, rises by the combined agencies of capillarity and endosmose, assisted by the exhalations from the leaves, which produce a diminished pressure in the upper part of the pores of the plant. The inferior animals are formed of cells, and they are supplied with food by imbibition and endosmose. In the superior animals, there is absorption, as is shown by the fact, that madder, taken by certain animals, penetrates their bones, coloring them red. A substance is more easily absorbed, provided that it wets the membrane. Fats which do not wet are not absorbed, but it has been shown by M. Bernard, that if they are formed into an emulsion with pancreatic sugar, that absorption takes place quickly. So Dr. Leze has observed that cod-liver oil (used as a medicine) acquires more energy, when made into an emulsion, because it is more completely absorbed. As with endosmose, it is observed that heat favors absorption, so also after an abundant transpiration or a bleeding, absorption is augmented.

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308. What is the distinction made between absorption and imbibition? What is said of the absorption in vegetable forms? Mention the causes which produce the ascent of liquids in the pores of plants. What is said of the inferior animals? What is said of the absorbability of gases, and emulsions, of cod-liver oil?

Gases.

309. **Gases** are æriform fluids, elastic, transparent, usually colerless and invisible. The force of cohesion has no activity in gases, whose molecules are self-repellent in consequence of the action of heat. *Tension* and *elastic force*, are expressions for the repulsive power of gases, specific in each case, and modified by varying conditions of temperature and atmospheric pressure.

310. **Gases and vapors.**—Æriform, or elastic bodies, are divided into two groups or classes, called respectively, (1.) Gases, and (2.) Vapors. In *permanent* gases, the elasticity or tension is such that they sustain all differences of temperature and pressure with only corresponding changes in bulk or volume. The gases now considered permanent, are the elements, oxygen, nitrogen, and hydrogen, and the compounds, oxyd of carbon and binoxyd of nitrogen.

Non-permanent gases.—In another large class of gases, chiefly compounds, cold and pressure, alone or united, are capable of overcoming the force of repulsion, and reducing them to the liquid state. Such are chlorine, ammonia, cyanogen, and sulphurous acid.

Vapors are formed by the action of heat upon liquids, and they retain the elastic or æriform condition, only so long as the temperature essential for their existence is maintained. It is assumed that the æriform state of bodies is, in all cases, due to the repulsive power given to their molecules by heat, and hence it follows, that by a sufficient degree of cold and pressure, all gases would be reduced to the fluid, or even to the solid condition. But in the present state of our knowledge, this truth has been only partially realized.

311. **Gases, simple and compound.**—The number of gases we are now acquainted with is thirty-four, of which four are simple, viz: oxygen, nitrogen, hydrogen, and chlorine. Seven gases are found free in nature, viz: oxygen, nitrogen, carbonic acid, light carburetted hydrogen, heavy carburetted hydrogen, sulphurous acid, and ammonia.

312. **The atmospheric air, its composition.**—The most common of all the elastic fluids is atmospheric air, which envelopes the earth in an ærial ocean, over forty-five miles in depth. Air is a mechanical mixture of the two simple elements, nitrogen and ox-

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309. What are gases? What is said of the force of cohesion? What of tension? 310. What is said of permanent gases? What of non-permanent gases? What of vapors? 311. What is said of simple and compound gases?

ygen, in the proportion, by volume, of 20·80 volumes of oxygen to 79·20 volumes of nitrogen. By weight it is composed of 23·01 parts of oxygen, and 76·99 parts of nitrogen; besides these, it contains small proportions of carbonic acid, carburetted hydrogen, &c., so that in 10,000 volumes of air, there are

Nitrogen,	7910
Oxygen,	2091
Carbonic acid,	4
Carburetted hydrogen,	4
Ammonia,	trace.
	10,000

313. **Atmospheric air the type of permanent gases.**—Nearly all of the mechanical properties of the air apply without modification to all the permanently elastic fluids. But some of these when applied to vapors, require to be restricted and modified by various circumstances. Air possesses, in common with liquids, the characteristic properties of fluids, such as the free motion of its particles among each other, the power of transmitting pressure in all directions, &c., while it is distinguished from solids and liquids by its great compressibility and elasticity.

314. **Impenetrability of air.**—Air is impenetrable. This may be shown by inverting a hollow vessel, as a tumbler, upon the surface of water; when pressed downward the water will not rise and fill the tumbler, because of the impenetrability of the air. The *diving-bell* depends on this quality of air: it consists of a large bell-shaped vessel, sunk by means of weights into the sea, with its mouth downwards. Notwithstanding the open mouth, and enormous pressure of the sea, the water is excluded from the bell, because of the air contained within.

315. **Inertia of air.**—Wind is only air in motion. If the air had no inertia, it would require no force to impart motion to it, nor could it acquire momentum. We know that the force encountered by a body moving through the air, (that is, displacing the air,) is in proportion to the surface exposed, and the velocity with which it is moving, (120.)

The sailing of ships, the direction of balloons, the wind-mill,

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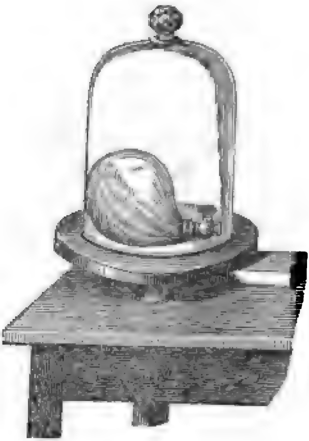
312. What is the composition of atmospheric air? Mention the proportion of its constituents in 10,000 parts. 313. What is said of the similarity of the air to all permanent gases? 314. How may the impenetrability of air be shown? 315. What is said of the inertia of air?

and the frightful ravages of the tornado, are all familiar examples of the power of moving air, and consequently proofs of the inertia of air.

316. **Expansive force of air.**—The molecular forces hold together the particles of solids in fixed positions, while they allow liquid molecules liberty to move in all directions. In gases, the molecular forces are completely subordinate to the repulsion imparted by heat. Under normal conditions, the atmosphere is in a state of equilibrium between the earth's attraction, and its own expansive force. If we disturb this condition of equilibrium, we see evidence of the exercise of the power of expansion. In fig. 193, a moist bladder, partly filled with air, is subjected to a partial vacuum under the air-bell. As the pressure in the bell is diminished by working the air-pump, the portion of confined air expands, and distends the flaccid bladder, which again contracts as soon as the equilibrium of pressure is restored by opening a communication with the external air.

193



317. **Weight of the air.**—If a vessel whose capacity is 100 cubic inches, be exhausted of air and weighed, and after filling it with dry air at the ordinary temperature and pressure, it is weighed again, it will be found that its weight is 31·011 grains more than at first; that is, 100 cubic inches of air weigh 31·011 grains. Air is the standard of comparison in density for all gases and vapors.

It is obvious that if we fill the globe, fig. 194, or any vessel of known capacity with any other gas than atmospheric air, we could ascertain the weight of a certain quantity of such gas, and by comparing this weight with an equal bulk of air, ascertain its density. Careful attention to a variety of circumstances (the more prominent of which

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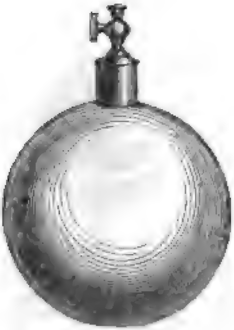
316. What is said of the expansive force of air? How may it be shown? 317. What is said of the weight of the air? How do we determine the density of the other gases?

are the temperature and atmospheric pressure) are necessary, in order to insure correct results.



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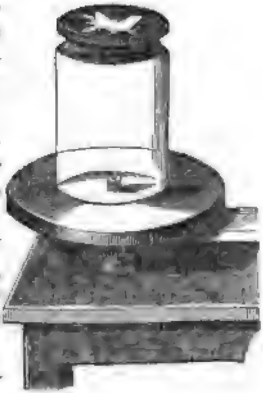
318. **Limits of the atmosphere.**—The atmosphere extends upward to a great height. Considering it as made up of successive layers or strata, since all of them are subject to gravitation, the lower layers must be compressed by those above them; consequently, the nearer we approach the earth, the more dense we find the air, and the higher we ascend, the more rarefied it is. As the air possesses a very great expansive force, we might suppose it would expand indefinitely toward the planetary spaces. But the expansive force of the air decreases as it is more dilated, and again it is diminished by the lower temperature, in the more elevated regions of space, so that an equilibrium is formed between the expansive force and gravity, which draws the particles toward the centre of the earth. Hence there is a limit to the atmosphere. From the weight of the atmosphere, its decrease of density as we ascend, and from certain optical phenomena, its height has been estimated to be about forty-five miles.



195

319. **Atmospheric pressure.**—That the atmosphere exercises a measurable pressure upon the earth, is well demonstrated by the glass vessel, fig. 195.

The upper part of this vessel is hermetically closed by a bladder; its lower edge rests upon the well ground plate of an air-pump. As the air is gradually exhausted, the surface of the bladder will become more and more depressed, until, finally, the membrane bursts, with a sharp report, owing to the pressure of the atmosphere upon it.

The above experiment only demonstrates the downward pressure of the

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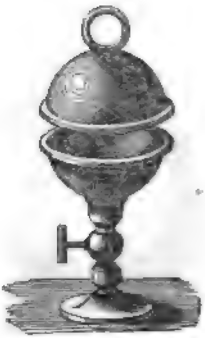
318. What is said of the limits of the atmosphere? Why does not the air expand indefinitely? What is the height of the atmosphere?

atmosphere. By the Madgeburgh hemispheres, it may be shown that the atmospheric pressure is exerted in all directions.

196



This apparatus is composed of two hollow hemispheres of brass, fig. 196, whose edges, accurately fitting, are well greased; one of the hemispheres is furnished with a stop-cock, with which connection is made with an air-pump. Upon placing them together upon the air-pump, and exhausting the air, it will be found that the hemispheres can no longer be separated, no matter in what position they may be held; proving that the atmospheric pressure which keeps the hemispheres together is exerted in all directions. Rings adapted to each hemisphere, enable two persons to test their strength against the atmospheric pressure.

320. **Measure of the atmospheric pressure.**—Although we have demonstrated the atmospheric pressure in the two preceding experiments, yet we have not estimated its amount; this was first done by Torricelli, a disciple of Galileo, in 1643. To repeat his experiment, a tube of glass closed at one end is selected, *A B*, fig. 197, about 32 inches in length. Holding the tube mouth upward, it is completely filled with mercury, and inverted, after closing the orifice with the thumb, with its lower end placed in a vessel containing mercury. The liquid column will, on removing the thumb, immediately fall some distance, and after several oscillations will come to rest at *n*, a height at the level of the sea, of about thirty inches above the level *a c*, of the mercury in the vessel. The space *n B*, above the mercury, is the most complete vacuum attainable by mechanical means, and is called the Torricellian vacuum. If, after having closed the mouth of the tube, we lift it out of the dish, we shall find that the weight of the column of mercury pressing against the finger is very considerable. When we place the tube in the vessel of mercury, we have this same force exerted, the column of mercury tending to flow out of the tube, and another force, the weight and pres-

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319. How may it be shown that the atmosphere exercises a pressure upon the earth? Describe the Madgeburgh hemispheres? What may be proved by them? 320. What was Torricelli's experiment? What is the Torricellian vacuum?

sure of the atmosphere, tending to push the mercury up in the tube. The length of the mercurial column, it is evident, is in proportion to the atmospheric pressure, and under ordinary circumstances, as we have seen, the atmospheric pressure is equivalent to a column of mercury thirty inches in height. We may now easily estimate the pressure on any given surface, as, for example, a square inch. If we should take a tube whose base is a square inch, and repeat the above experiment, the column *a n* would, as before, be sustained at a height of thirty inches; but the weight of a column of mercury thirty inches in height and one inch square, is very nearly fifteen lbs.; therefore the atmospheric pressure on a square inch is fifteen lbs.

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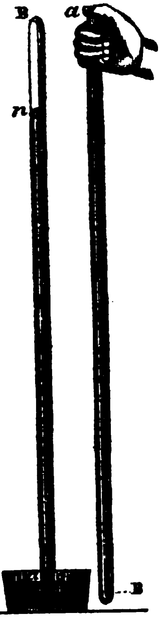

If the tube were filled with a lighter liquid than mercury, a proportionally longer column would be sustained by the pressure of the atmosphere: the length of the column being inversely as the densities of the two fluids. If water, which is about 13·5 times lighter than mercury, was used, the column of water sustained would be 13·5 times as long as the mercurial column, or about thirty-four feet.

321. **Pressure upon the human body.**—The air, as we have seen, transmits pressure equally in all directions; consequently every object exposed to the atmosphere at sea level, is pressed upon all parts of its surface, with a force amounting to fifteen lbs. to the square inch. The surface of a human body of average size, measures about 2000 square inches; such a body sustains, therefore, a pressure of 30,000 lbs., or fifteen tons. It would seem, at first, that such a pressure would crush the individual subjected to it, but this great force is entirely neutralized, because the atmospheric pressure is equal in all directions. All the cavities and pores of the body are filled with counteracting air, which presses with an equal force in every direction.

How may the pressure on any given surface be estimated? What is the atmospheric pressure in a square inch of surface? What would be the effect if a lighter liquid than mercury was used? 321. What is the pressure upon the human body? Why does not this pressure crush individuals subjected to it.

822. **Construction of barometers.**—Barometer is the name given to Torricelli's tube. This instrument has different forms, according to the use for which it is designed. There are, however, certain conditions to be fulfilled in the construction of barometers, whatever may be their form.

1st.—It is necessary that the mercury be perfectly pure and free from oxyd, otherwise it adheres to the glass; again, by impurities, its density is changed, and the height of the column in the barometer is greater or less than it should be.

2d.—It is necessary that there be a perfect vacuum above the surface of the mercury in the tube; for if there be a little air, or vapor, as of water, the elasticity of these will continually depress the mercurial column, preventing its rising to the true height.

To obtain a perfect vacuum, a small portion of pure mercury is boiled in the barometer tube, and when cooled, another portion of mercury is added, and again boiled, and so on, until the tube is full; by this means the air and moisture which adhered to the walls of the tube are driven out, completely. The boiling must not be too long continued, otherwise a portion of oxyd will be formed, which will dissolve in the mercury and alter its density. The tube being filled, we invert it in a vessel of pure mercury. In order to determine whether there is not some air or moisture in the tube, we incline the tube quickly; if the mercury gives a dry metallic sound when striking the summit of the tube, it is a proof of their absence, while, if they be present, the sound is deadened.

823. **Pascal's experiments.**—The experiment of Torricelli excited the greatest sensation throughout the scientific world, and the explanation he gave of it was generally rejected.

Pascal, who flourished at that time, perceived its truth, and proposed to subject the experiment to a test which must put an end to all further dispute. "If," said Pascal, "it be really the weight of the atmosphere under which we live, that supports the column of mercury in Torricelli's tube, we shall find by transporting this tube to a loftier point in the atmosphere, that in proportion as we leave below

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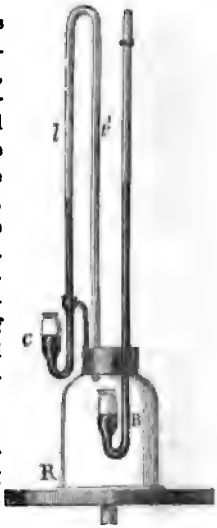
822. What is a barometer? What are the necessary conditions to be fulfilled in the coustruction of barometers? How is a barometer filled with mercury? How may it be determined whether the interior of the tube is free from air and moisture? 823. What is said of Pascal's experiment? How was it conducted?

more and more of the air, there will be a less column of mercury sustained in the tube." Pascal therefore carried a Torricelli tube to the top of a lofty mountain, called the Puy-de-Dome, in Auvergne, (central France.) It was found that the column gradually diminished in height as the elevation to which the instrument was carried increased. He repeated this experiment at Rouen, (France,) in 1646, with a tube of water, and found that the column was sustained at a height of about thirty-four feet, or 13·5 times greater than the height of the column of mercury.

324. **Apparatus illustrating the principle of the barometer.**—By means of the air-pump and the apparatus, fig. 198, the principle of the barometer is beautifully shown.

The apparatus consists of a large bell glass, *R*, with two syphon barometer tubes attached. One of them, *B*, has its cistern within the bell. The other barometer, whose cistern is without the bell, communicates with its interior by the curved tube *l l'*. When this apparatus is placed on the air-pump, and exhausted of air, the mercury in *B* falls in proportion to the vacuum produced, and rises in the tube *C l*, in the same proportion. In *B* we see the effect of diminished pressure, as on a mountain or in a balloon; in *C* the pressure of the external air caused the mercury in it to mount, forming a gauge of the exhaustion. When the air is allowed to enter, the mercury in the tubes resumes its former position.

198



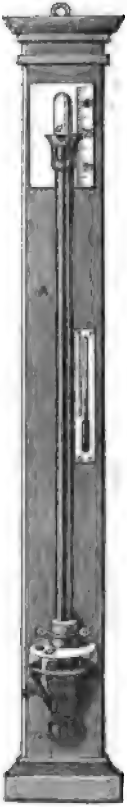
325. **Height of the barometric column at different elevations.**—The following table gives a comparative view of the height of mercury in the barometer at different elevations above the sea.

What is said of his experiment with a tube of water? 324. Describe the apparatus illustrating the principle of the barometer. 325. Mention the height of the barometer at the elevation of 5000 feet, of 10,000 feet, of 6 miles, &c.

At the level of the sea, the mercury stands at		31 inches.
5,000 feet above " " " "	" "	24·797 "
10,000 " [height of Mt. Ætna,]	" "	15·000 "
15,000 " [height of Mt. Blanc,]	" "	16·941 "
3 miles	" "	15·000 "
6 " [above the top of the loftiest mountain,]		7·500 "
9 "		3·750 "
15 "		1·875 "

326. **Cistern barometer.**—The cistern barometer is the most simple form of this useful instrument. It consists of a Torricelli's tube of glass, filled with mercury and plunged into a vessel containing the same metal; this vessel or cistern is of various forms.

199



That it may be transported easily, the cistern is divided into two compartments, *m*, *n*, fig. 199, the upper division is cemented to the tube, communicating with the atmosphere by the small hole *a*. The two compartments are united by the narrow neck into which the lower part of the barometer tube enters, fitting closely, although not touching the walls; leaving only so small a space, that capillarity will not allow the mercury to escape from the lower compartment when we incline the barometer. So that in whatever position we place it, no air can enter the lower end of the tube.

This barometer is always fixed on a wooden support, at the upper part of which is a graduated scale, whose zero is the level of the mercury in the cistern. The sliding scale *i* indicates the level of the mercury in the tube. There is attached to barometers also a slider, moving by the hand upon which is a *vernier*, by means of which we can distinguish very small variations. But the level of the mercury in the cistern varies as the column of mercury in the tube ascends or descends, for then a certain quantity of mercury passes from the cistern into the tube, or the reverse, so that the zero (the level) changing the graduation on the scale, does not indicate the true height of the barometer.

327. **Fortin's barometer.**—This error is avoided in

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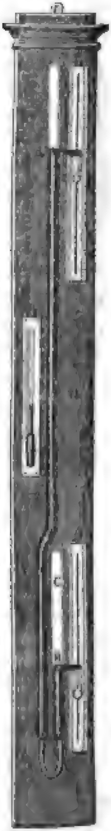
326. What is said of the cistern barometer? Describe the form shown in fig. 199. How is it mounted?

the barometer of Fortin, which differs from the cistern barometers only in the cistern. Fig. 200, represents this cistern.

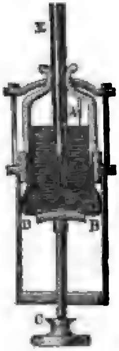
201



The lower part is of deer-skin, and is elevated or depressed by means of the screw, *C*, pressing the plate *DB*. At the upper wall of the cistern is fixed a small ivory needle, *A*, whose point corresponds exactly to the zero of the scale, graduated on the case. At each observation with this instrument, care is taken to make the level of the mercury in the cistern, correspond with this point, which is accomplished by turning the screw up or down. This form of Barometer has been adopted by the Smithsonian Institution, and is made by Green, of N. Y.

828. **Gay Lussac's barometer.**—Gay Lussac's syphon barometer, fig. 201, consists of two tubes of the same internal dimensions, united by a very capillary neck, both closed at their upper part, the air entering the cistern through the hole *a*. The large tubes being of the same interior diameter, the capillary action is mutually destroyed. The capillary tube is made small, so that when we turn the instrument over, it remains full, because of its capillarity. For measuring the height of the mercury, there are two scales, *E* and *D*, graduated in different directions, having their common zero at *O*, on a line intermediate between the two mercurial surfaces; so that by adding the indications of these two scales, we have the difference in the level of the mercury in the two tubes. But a quick movement, transportation in a carriage or on horseback, may divide the mercurial column in the capillary tube, and thus allow the air to pass into the long arm, whereby the accuracy of the instrument would be destroyed.

200



In order to obviate this inconvenience, M. Bunten has modified the instrument as represented in fig. 202. The long arm *A* drawn out to a point, enters into and is soldered to a larger tube, *K*, which is

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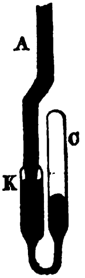
827. Describe the cistern of Fortin's barometer. 828. What is said of Gay Lussac's barometer? How is the instrument graduated?

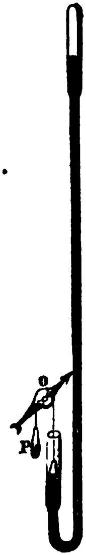
attached to the capillary tube. With this arrangement, should bubbles of air even pass through the capillary tube, they cannot enter the long arm, but are retained in the top of *K*. These bubbles of air have no influence on the observations, and may be driven out by simply heating the tube.

202



329. **Wheel barometer.**—The wheel barometer is an instrument of no scientific value, but has a certain popular interest as it purports to declare the state of the weather. The apparatus consists, fig. 203, of a dial plate attached to a syphon barometer having a small cylindrical cistern, upon whose surface rests a float; this is attached to a silk string, which winds around a pulley, *O*, and is terminated by the counterpoise *P*; the axis of the pulley carries a needle, which rests upon the face of the dial plate. When the pressure of the atmosphere changes, the column rises or falls in the tube accordingly, and carries along with it the float. The pulley turns and moves the needle to the words rain—fair—changeable, &c., which are designed to correspond to certain heights of the mercurial column.

203



330. **Causes of error.**—In order to obtain the true height of the mercury in a barometer, we must, after making the observation, determine by calculation the error caused by *capillarity*, and by the variations of density, caused by *changes of temperature.*

331. **Correction for capillarity.**—When the barometer tube is of capillary diameter, the surface of the mercury in it becomes convex (290) and the depression is greater by as much as the tube is more capillary. For correcting this error, it is necessary to know the diameter of the tube, and then by means of the table, (292,) ascertain the depression, which must always be added to the observed height.

332. **Correction for temperature.**—In all mercurial barometers, we must have regard to the temperature, for as heat expands mercury, it diminishes its density, and in consequence, under the same atmospheric pressure the mercury would rise as much higher as the temperature was more elevated. Consequently baro-

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What is Bunten's improvement? 329. What is said of the wheel barometer? How are the movements of the mercurial column indicated? 330. What are causes of error in making thermometric observations? 331. What is said of the correction for capillarity?

metric observations cannot be compared, unless they were taken at the same temperature, or are brought by calculation to the same. As it is entirely arbitrary what temperature shall be chosen, that of melting ice has generally been taken. A table showing the expansion and contraction of mercury at different temperatures may be found in the section upon heat.

333. **Aneroid barometer.**—This instrument, invented by M. Vidi, is a barometer without mercury, and possesses the advantage over others of having a small size, of being exceedingly portable, and of giving sufficiently accurate indications for most purposes. It consists of a circular copper box, the cover of which is very thin, and which is hermetically sealed, after the air is exhausted from its interior. This is contained in a metal box, fig. 204, about four inches in diameter, and which has a dial plate like that of a watch. Variations in the pressure of the atmosphere, will cause the cover of the exhausted box to be more or less depressed. By means of a combination of levers and springs, the movements of the centre of this cover are communicated to a pointer which moves over the graduated plate.

204

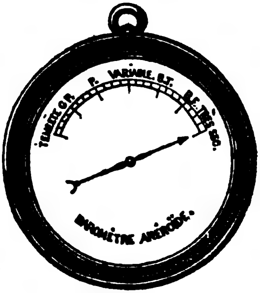
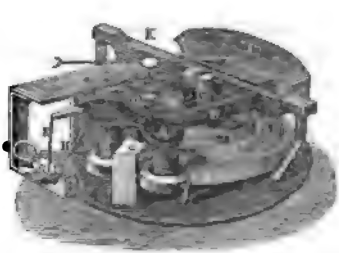


Fig. 205, shows the interior construction of this instrument. To the cover *M*, of the exhausted box, are attached two uprights, *S*, which act upon a lever, *P*, by means of a pin which unites them. This lever, (*P*,) is attached to a bar, *K*, which moves freely on two pivots, placed at its extremities. A lever *B*, unites the bar *K*, to the plate *A*, which presses on two springs. By means of a spring, represented in the figure, the rod *E*, in connection with *A*, communicates any movement to the bent lever *H*, which causes a metallic wire to uncoil itself

205



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332. What is said of the correction for temperature? 333. What is said of the aneroid barometer? What does it consist of? Describe its interior construction.

from the axis *O*, of the pointer, and which thus transmits any movement to it.

334. **M. Bourdon's metallic barometer.**—M. Bourdon, of Paris, has invented a barometer which, with great simplicity of construction, has all the advantages of the aneroid. The essential part of the instrument, fig. 206, consist of a very thin and elastic brass tube *A*, bent into the form of an arc of a circle. This tube, exhausted of air and hermetically closed, is attached only at its centre, so that the ends are free to move. With a diminished atmospheric pressure, the ends separate from each other. If the atmospheric pressure increases, the ends come nearer together. By means of the metallic wires *a*, *b*, and the spring, *c*, these movements of the ends of the tube are communicated to a needle moving over a graduated plate.

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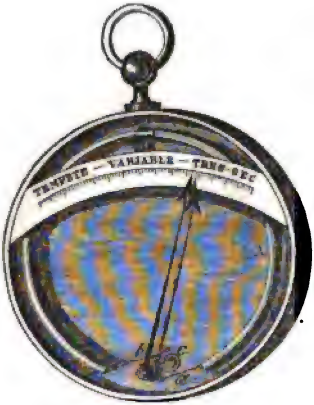

The same principle Bourdon has applied to the construction of manometers for locomotives and other steam boilers, and they are now extensively used.

335. **Variations of the barometric height.**—When we observe a barometer during many days, we notice that not only does its height vary from day to day, but also in the same day. The amount of these variations increases from the equator towards the poles. The greatest variations, (excepting extraordinary cases,) are 6 m. m. (·2362 in.) at the equator; 30 m. m. (1·181 in.) at the tropic of cancer; 40 m. m. (1·5748 in.) in France, and 60 m. m. (2·3622 in.) 25° from the poles. The greatest variations take place in winter.

The mean diurnal height is the average of twenty-four successive observations, taken from hour to hour. M. Ramond has found the

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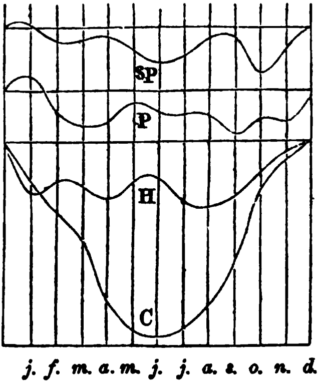
334. What is said of Bourdon's metallic barometer? Describe its construction. 335. What is said of barometric observations? What are the greatest variations? When are they greatest? What is the mean diurnal height? What the mean annual height?

height of the barometer at noon to be the mean of the day. *The mean monthly height* is the average of the thirty mean daily heights of a month. *The mean annual height* is the average of the three hundred and sixty-five mean daily heights of a year.

At the equator the mean annual height is 758 m. m. (29·483 in.) It increases, passing from the equator, and attains its maximum of 763 m. m. (30·04 in.) between the latitudes of 30° and 40°; it decreases in more elevated latitudes. The mean monthly height is greater in winter than in summer, because of the cooling, and consequent increased density of the atmosphere.

207



The scale, fig. 207, shows the barometric variations of the different months. Equal distances, taken on the lower horizontal line *j—d*, represent the duration of the different months, and the curved lines at the commencement of each interval, the mean barometric heights corresponding to the successive months. We have then curves, whose inflexions make known the variations of the mean from one month to another. The four curves represent the monthly means as observed at Calcutta, *C*, at Havana, *H*; Paris, *P*, and at St. Petersburg, *S P*. The difference of the curves represent, with great distinctness, the differences of the mean barometric heights. Calcutta and Havana, on the same latitude, have, it will be seen, very different monthly means.

336. Variations observed in barometers are of two kinds.

1st.—**Accidental variations**, which do not offer any regularity in their movements, and which depend on seasons, the direction and geographical position.

2d.—**Diurnal variations.**—It was about the year 1722, that the hourly variations of the barometer were proved to take place in a regular manner. From that time, many observers have labored to determine the extent and the periods for the different parts of

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What is said of the mean annual height at the equator and at other points? What is said of the mean monthly height in winter? Describe fig. 207. 336. What is said of accidental variations? Mention Humboldt's observations on diurnal variations.

the earth. Alex. Humboldt, with others, has demonstrated by a long series of very accurate observations at the equator, that the maximum of height corresponds to 9 o'clock in the morning; the barometer then falls to its minimum at four, or half-past four o'clock in the afternoon; it then rises, attaining a second maximum about ten o'clock at night. These movements are so regular they almost serve to mark the hours like a clock, but they are very small. M. Humboldt found that the distance between the highest point in the morning, and the lowest point in the afternoon, was but two m. m. In the temperate zones, these diurnal variations also take place, but are very difficult to ascertain, because of the accidental variations, so that it requires extended and very accurate observations in order to determine them. The hours of the maximum and minimum of the diurnal variations, appear to be nearly the same in all climates, varying a little with the season. Thus in winter, (in France,) the maximum is at nine o'clock in the morning, the minimum at three o'clock in the afternoon, and the second maximum at nine o'clock in the evening. In summer, the maximum takes place before eight o'clock in the morning, the minimum at four o'clock in the afternoon, and the second maximum at eight o'clock at night. In spring and in autumn, the critical hours are intermediate.

337. **Relation between barometric changes and the weather.**—Those variations of the barometer which are not periodic, are generally supposed to be indications of changes in the weather. For it has been noticed that those days in which the column of mercury was 29·72 inches in height, there was very changeable weather; that in a majority of those days when the mercury rose above this point, there was fine weather, when it fell below this point, stormy weather, snow or rain, prevailed. It is from these coincidences between the height of the barometer and the state of the weather, that there is marked on the scale or dial plate of barometers, at certain heights, the words stormy, rain or snow, variable, fine weather, &c., and it is supposed that when the mercury stands at the height indicated respectively by these words, we should have corresponding weather: now although this may be true to a certain extent, yet a little reflection will

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What is said of the maximum and minimum diurnal variations? 337. What is said of the relation between barometric changes and the weather? By what are changes of the weather indicated in the barometer?

show the fallacy of such indications. The height of the mercurial column varies with the position of the barometer, and consequently two barometers, in different places, not upon the same level, would indicate different coming changes. The changes of weather are indicated in the barometer, not by the actual height of the mercurial column, but by its changes of height.

338. **Rules by which coming changes are indicated.**—The following rules may, to some extent, be relied upon, but for reasons already stated, must be taken with a considerable degree of allowance.

1.—When the mercury is very low, high winds and storms are likely to prevail.

2.—Generally the rising of the mercury indicates the approach of fair weather; the falling of it shows the approach of foul weather.

3.—In sultry weather the falling of the mercury indicates coming thunder. In winter, the rise of mercury indicates frost. In frosty weather, its fall indicates thaw, and its rise indicates snow.

4.—Whatever change of weather suddenly follows a change in the barometer, may be expected to last but a short time.

5.—When the barometer alters slowly, a long succession of foul weather will succeed if the column falls, or of fair weather if the column rises.

6.—A fluctuating and unsettled state in the mercurial column, indicates changeable weather.

339. **Measure of heights by the barometer.**—Since the level of the mercury in the barometer falls, as we ascend above the earth, we see that it is possible to determine by barometric observations, the elevation of a mountain, or of any other place above or below the level of the sea. If the atmosphere had a uniform density, we could ascertain, by a very simple calculation, the height to which the barometer was raised, from the amount of the fall of the mercurial column; for mercury, being 10,466 times heavier than air, a fall of one m. m. (0·3937 in.) of the barometric column, would indicate that the column of air had diminished 10,466 m. m., (412·054 in.) and therefore the height measured would be 10,466 m.m. But as the atmospheric pressure dimishes very rapidly in density as we ascend, such calculations are of no value

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338. Mention the rules by which coming changes are indicated?
339. What is said of the measurement of heights by the barometer?

except for small elevations, and it is necessary to determine the rate of diminution in density of the air, in proportion as it is further removed from the earth. Formulæ have been given by means of which we can, for any given latitude, at once calculate from the barometric observation the real height. Tables have also been constructed by which we can easily calculate the level between any two places, when we know the height of the barometer and the temperature of the atmosphere.

340. **Balloons.**—Bodies in air (like solids plunged in liquids) lose a part of their weight, equal to the weight of the air displaced. From this it follows, that if a body weighs less than an equal volume of air, it will rise in the atmosphere until it meets with air of its own density: hence heated air, smoke, &c., rise, because they are less dense than cold air.

Dr. Black, of Edinburgh, announced in 1767, that a light vessel filled with hydrogen gas would rise in the air; and Cavallo, in 1782, communicated to the Royal Society in London the fact, that soap bubbles, filled with hydrogen, would ascend in the atmosphere. The brothers Montgolfiers, in 1782, first constructed balloons. These consisted of globes of cloth, lined with paper. The one that they first exhibited publicly, was a globe about thirty feet in diameter, open at the lower part, below which was placed a fire. This, expanding the air within the globe, diminished its density, and the balloon rose to a height of nearly a mile. Hot air balloons are, therefore, (in allusion to their inventors,) usually called Montgolfiers. Balloons filled with hydrogen were first introduced by Mr. Charles, professor of physics in Paris, in 1782, and in November of the same year, Pilatre de Rozin made the first ærial voyage, in a balloon filled with hot air. The ascension took place from Boulogne. Soon after, M. M. Charles and Robert, in the garden of the Tuilleries, repeated the same experiment in a balloon filled with hydrogen gas. At this epoch, ærial voyages multiplied. In January, 1784, seven persons rose from Lyons, three from Milan, &c., and soon, so familiarized were the public with this method of navigating, that it was not uncommon for people to ascend in a balloon which was restrained from going too far by means of a cord; when the adventurers had attained a certain height, the balloon was drawn down by means of the cord, and other voyagers took their place.

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340. Why do bodies lighter than air rise in the atmosphere? Mention Dr. Black's, and Cavallo's observations. What is said of the brothers Montgolfiers? Who constructed the first hydrogen balloons? What is said of other æronauts?

Gay Lussac, in 1804, made an ascent remarkable for the facts with which it enriched science, and for the height which was attained, namely, about 23,000 feet. In those elevated regions, Gay Lussac found respiration and the circulation of the blood much accelerated, because of the rarefaction of the atmosphere, his heart making 120 pulsations in a minute, while 66 was its normal rate. He also collected there, specimens of air for chemical analysis.

341. **Construction and filling of balloons.**—Generally the balloon is pear-shaped. It is made of material impervious to hydrogen gas, often of strips of taffety sewed together, and covered with a varnish, composed of linseed oil and caoutchouc, dissolved in essence of turpentine, or of a tissue formed of a layer of caoutchouc interposed between two layers of taffety, and called *mackintosh.*

To fill the balloon, *A,* an aperture at its lower end is placed in communication, by means of a tube, *t,* with vessels, *t,* generating hydrogen, (from the action of dilute sulphuric acid and zinc, as shown in fig. 208.) When the balloon is sufficiently filled, the aperture is closed. Suspended by means of a net work of ropes covering the whole apparatus, is a boat formed of wicker-work, for the re-

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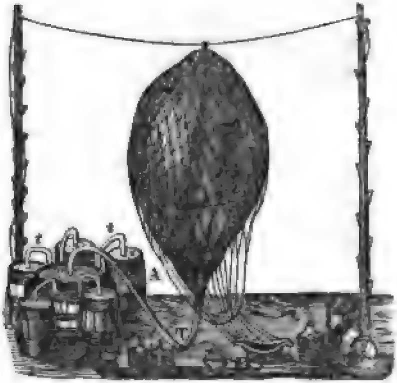
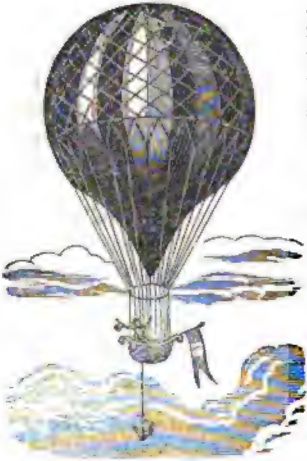


What is said of Gay Lussac? 341. Of what are ballons constructed? How are balloons filled?

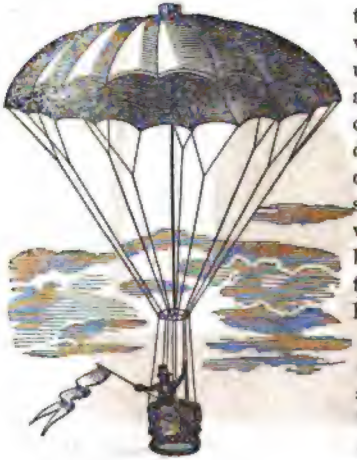
209



ception of the æronauts, fig. 209. At the upper part of the balloon is a valve, which the manager may open or shut at pleasure by means of a cord. As illuminating gas can often be procured more easily than hydrogen, it is frequently used by æronauts, but being more dense than pure hydrogen, the balloon requires to be of a correspondingly larger size, in order to obtain the same ascensional force.

The balloon must not be completely filled, for the atmospheric pressure diminishing upwards, the gas in the interior will expand in a like ratio, and tend to burst the balloon. A number of fatal accidents have taken place from this cause.

210



When the æronaut wishes to descend, he pulls the cord which opens the valve in the upper part of the balloon, and thus the hydrogen escapes, and the balloon comes down. If he wishes to ascend, he throws out bags of sand which he has taken up with him, and the balloon, becoming thus lighter, rises to a correspondingly greater height.

342. **Parachute.**—Æronauts often abandon their balloons, and descend in a *parachute*. This apparatus is composed of strong cloth, and when extended, has the appearance of an umbrella, fig. 210, with this

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What is the objection to the use of illuminating gas in balloons? How can the æronaut regulate his voyage? 342. What is a parachute?

difference, that the whale-bones are replaced by cords, sustaining a small boat, in which the æronaut places himself. There is a small chimney, or hole, in the top of the parachute, in order to allow the air, which would accumulate, to escape regularly, otherwise it would escape fitfully by the sides, throwing the apparatus violently around, to the imminent peril of its occupants.

343. **Law of Mariotte.**—Boyle and Mariotte discovered the law of the compression of gases, which is as follows:

At the same temperature, the volume occupied by the same bulk of air, is in inverse ratio to the pressure which it supports. From which it follows, that the density and tension of a gas are proportional to the pressure. In order to verify this law, the apparatus called Mariotte's tube is employed. To an upright support of wood is attached a bent tube, fig. 211, whose two vertical branches are unequal in length. The longer limb is open at the top, and furnished with a scale which indicates heights; the shorter is closed at the top, and is divided into parts of equal capacity. Mercury is poured into the tube so that the level of the liquid in the two branches is found on the same horizontal line, *l a*. The air in the shorter limb then occupies a definite volume, indicated by the graduation. If more mercury is added, until the measured volume of air is reduced one-half, as from ten to five, occupying only the space above *l'*, and we now measure the difference of level between the two surfaces of mercury, viz: *a' h*, we shall find that it is precisely the same as the height of the barometric column. That is, the pressure of the column of mercury in the Mariotte's tube is equivalent to one atmosphere; adding this pressure to that which the atmosphere exerts on the mercury, we have the air subjected to double of its usual pressure, and it is, consequently, reduced in volume one-half. If we subject it to

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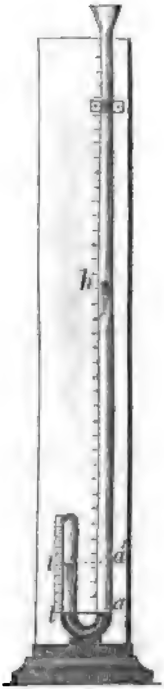

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343. What is the law of the compression of gases discovered by Mariotte? How may this law be demonstrated?

a pressure of three atmospheres it will be reduced to one-third; of four atmospheres, to one-fourth of its original bulk, &c. At a pressure of 770 atmospheres, air would become as dense as water.

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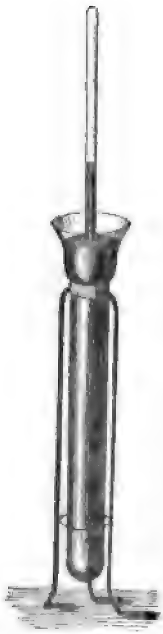

The law of Mariotte may also be verified for pressures less than one atmosphere, by using a barometer tube, about two-thirds filled with mercury, and inverted in the deep cistern, fig. 212, filled with mercury. Sinking the tube to such a depth that the level of the mercury within and without is the same; the contained air is under the pressure of one atmosphere, and occupies a known volume. If the tube is now raised until by a diminution of pressure the given volume of air is doubled, it will be found that the length of the mercurial column in the tube is half that in the barometer: that is, the air under a pressure of one-half an atmosphere has doubled its volume. The volume here, as in the other case, is in inverse ratio to the pressure.

344. **Limits of the law of Mariotte.**—The law of Mariotte is true for air, under very variable pressures, at very low and at very high temperatures. But it is not probable that it prevails at all pressures, and at all temperatures: since almost all gases, by a certain amount of pressure are liquefied. Certain gases are liquefied by cold alone, at the ordinary pressure, others by pressure and cold combined. Mariotte's law fails for most gases at very great pressures, and at very low temperatures, and probably also for very small pressures and very high temperatures; for the repulsion of the molecules, probably, does not exist when they have been separated a certain distance by rarefaction, obtained by a great diminution of pressure or elevation of temperature, or by the two combined.

Mariotte's law, therefore, does not hold good for all gases, above all, for those which are liquefied by compression. M. Pouillet has concluded from his experiments, in which the pressure obtained was equal to 100 atmospheres, that the five gases which have not been liquefied, namely, oxygen, nitrogen, hydrogen,

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Describe another method for illustrating this law for small pressures. 344. What is said of the limits of the law of Mariotte?

carbonic acid, and binoxyd of nitrogen, obey the law of Mariotte. He found that sulphurous acid, ammonia, carbonic acid, protoxyd of nitrogen, heavy carburetted hydrogen, and light carburetted hydrogen, were compressed more than air, and that this difference augmented with the pressure.

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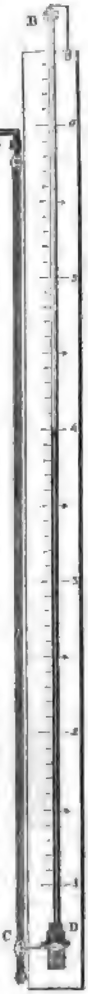


345. **Manometers.**—Manometers are instruments designed to measure the tension of gases or vapors above the atmospheric pressure. The unit of measurement which has been chosen for these instruments is the pressure of the atmosphere, which at the level of the sea, is (320) equal to about 15 lbs. to the square inch, and therefore a pressure of two or of three atmospheres signifies a pressure of 30 lbs., or of 45 lbs. Manometers are of very various construction, two of which will be mentioned, namely:

346. 1st.—**Manometer with free air.**—This consists of a glass tube, *B D*, fig. 213, open at both ends, placed in a cistern of mercury, to which it is cemented. The cistern is connected with an iron tube *A C*. By this tube the pressure of the fluid is transmitted to the mercury. The gases whose tension we wish to find, being often of a temperature sufficiently high to melt the cement attached to the apparatus, the tube *A C*, is filled with water, which receives the pressure, direct, and transmits it to the mercury.

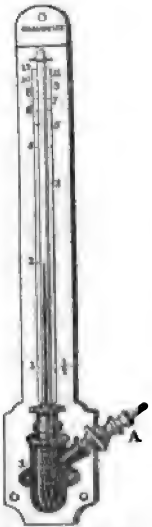
In order to graduate this instrument, *A* being open to the atmosphere, that point where the mercury rests in the tube is marked 1, (one atmosphere.) At distancesof thirty inches, the numbers 2, 3, &c. are marked, which indicate the number of atmospheres, for it will be remembered, that a column of mercury thirty inches in height represents the atmospheric pressure. The apparatus being placed in connection with a steam boiler, we ascertain the pressure to which it is subjected by the height to which the mercury rises in *B D;* if to 2·5, the pressure is 2·5 atmospheres, or 37½ lbs. to the square inch.

What is said of gases at great pressures and low temperatures? Mention the result of Pouillet's experiments on the unliquefiable gases. 345. What are manometers? What is the unit of measurement in manometers? 346. Describe the construction of the manometer with free air.

Endless forms of manometers, under the popular name of "*steam gauges*," are in use upon steam boilers—in which the pressure, acting upon a spring or opening spiral, moves an index over a graduated clock-face, upon which experimental pressures are registered. Of these instruments, that known as Ashcroft's steam gauge, appears to meet with most general favor among steam engineers, being in fact quite identical with Bourdon's metallic barometer, already described, (334.)

347. 2d.—**Manometer with compressed air.**—This form of the instrument consists of a glass tube filled with dry air, placed in a cistern of mercury, to which it is cemented. This by a lateral tube, *A*, fig. 214, communicates with the vessel containing the elastic fluid to be examined.

214



In order to graduate the manometer, such a quantity of air is placed in the tube, that when *A* communicates with the atmosphere, the level of the mercury is the same in the tube as in the cistern. At this point, therefore, 1 is marked upon the scale. Following Mariotte's law, it might be supposed that we should mark for two atmospheres, at a point in the middle of the tube, but when the column of air is reduced half, the tension of two atmospheres is increased by the weight of the column of mercury raised in the tube, and therefore the middle point of the tube would represent a pressure greater than two atmospheres. The true position for the second mark is at a point a little below the middle of the tube, where the elastic force of the compressed air, added to the weight of the column of mercury, is equal to two atmospheres.

By calculation, the true position of the points indicating 3, 4, &c., atmospheres, is determined on the scale of the manometer. This is not a very desirable form of the instrument, because the volume of air growing smaller, the divisions must continually diminish in size, and therefore, even considerable variations of pressure, are not easily observed in the upper portion.

348. **Diffusion of gases.**—It has been seen, (249,) that liquids mixed together, gradually separate, and lie superimposed in the order of their densities, and that the surfaces of the separation

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347. Describe the manometer with compressed air. How is the tube graduated? What is the objection to this form of instrument?

of the liquids are horizontal. But when gases are mixed, they present other conditions of equilibrium, as follows.

1.—*A homogeneous and persistent mixture is formed rapidly, so that all parts of the same volume are composed of the same proportions of the mixed gases.*

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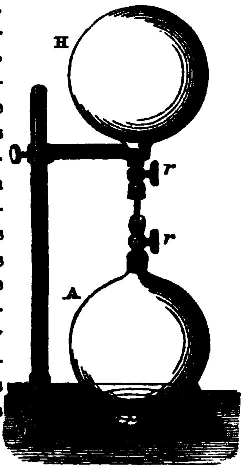

Berthollet demonstrated this law of Dalton, with the apparatus seen in fig. 215. He filled the balloon, *A*, with carbonic acid gas, having a density 1·529, connected by means of a tube with another balloon, *H*, filled with hydrogen, the stop-cocks *r*, *r*, being closed, the apparatus was placed in the vaults of the Observatory at Paris, where there is a uniform temperature. When the balloons had exactly this temperature, their stop-cocks were opened, and after a time there was found in each balloon a uniform mixture of hydrogen and carbonic acid; notwithstanding the great difference in density between the two gases, carbonic acid being 22 times as heavy as hydrogen. This interpenetration, or movement of gases toward one another, is called *diffusion*.

2.—*In a mixture of gases, the pressure, (or elastic force,) exercised by each of the gases, is the same as it was when alone.*

This law may be demonstrated by filling a number of tubes over mercury with different dry gases, having their volume, and the pressure to which they are subjected equal; upon decanting these gases into a graduated vessel filled with mercury, the pressure will be as before, and the volume, equal to the combined volume of all the gases, proving the law stated.

The rapidity with which the diffusion takes place, varies with the specific gravity of the gases. The more widely two gases differ in density, the more rapid is the process of intermixture.

This law is stated by Prof. Graham as follows:

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348. What is the first law of the diffusion of gases? How did Berthollet demonstrate this? What is the second law of the diffusion of gases? How may this law be demonstrated? Upon what does the rapidity of the diffusion depend?

3.—*The velocities with which gases diffuse themselves, are in inverse ratio to the square root of their specific gravities.*

Prof. Graham used a tube about half an inch in diameter, and from six to fourteen inches in length, fig. 216. The tube was closed with plaster at its upper end, and filled dry, with the gas to be examined, and its lower end placed in water. The air and gas both passed through the plaster, and the water ascended in the tube. Care was taken to maintain the surface of the water within and without the tube on the same level, in order that the results might not be modified by the disturbing force of gravity. The tube being filled with hydrogen, it was found that while one volume of air was passing into the tube, 3·83 volumes of hydrogen were passing out. This is the amount which the above law requires, for the density of the air being one, its square root is one, and its diffusiveness one. The density of hydrogen is 0·069, its square root is 0·02632 and its diffusiveness is $\frac{1}{0{\cdot}02632}$ — 3·7984, instead of 3·83, as determined by experiment.

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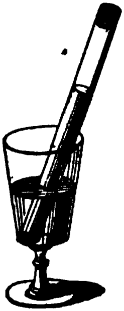

The uniform composition of our atmosphere, (312,) is a wonderful illustration of the prevalence of the law of diffusion, or interpenetration of gases. Under all circumstances, and at all heights, over the sea, and on the loftiest mountains, we find the same proportions in its several constituents, not excepting those minor ones which might at first appear to be due to local causes.

349. **A striking method of illustrating the diffusion of gases,** is by the apparatus, fig. 217. This consists of a porous earthenware cell, (from a Bunsen's battery,) to the open mouth of which is cemented a funnel, whose barrel is lengthened by a glass tube. Supporting the end of the tube, by means of a clamp, in the lower vessel—containing colored water—and holding over the porous cell a bell jar filled with hydrogen; bubbles of gas will escape rapidly from the tube through the water. If the hydrogen bell is removed, the colored water immediately rises in the tube. The effect is due to the diffusive action taking place between the air in the porous cell and the hydrogen in the jar,

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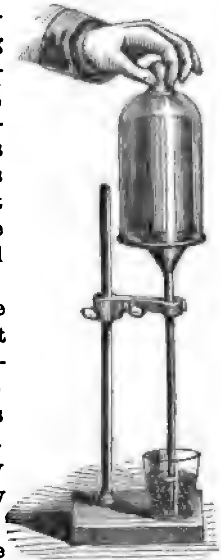
How did Prof. Graham perform his experiments? 349. What other apparatus is described? What is the influence of temperature on the diffusion of gases?

for as the hydrogen passes into the cell more rapidly than the air passes out, consequently the volume in the cell is increased, and the excess escapes through the water. Upon removing the bell of hydrogen, the conditions are reversed; the cell now contains hydrogen, which diffusing itself into the air more rapidly than the air enters the vesesl, causes a diminution of volume, and the water rises in the tube. After a short time, perfect equilibrium is restored, the water in the tube assuming the level of that contained in the vessel.

217



By an elevation of temperature, the rate of diffusion of equal volumes of different gases, becomes accelerated, for heat diminishes the density of all gases, but the rate of diffusion does not increase as rapidly as the expansion of gases by heat, consequently the same absolute weight of any gas will be diffused more rapidly at a low than at a high temperature.

350. **Table of diffusion of gases.**—The following table gives the specific gravity of the several gases, the square root of their density, the reciprocal of that square root, (*i. e.* the calculated diffusiveness of the gas,) and the actual numbers obtained by experiment.

DIFFUSION AND EFFUSION OF GASES.

Name of gas.	Specific gravity.	$\sqrt{\text{Density.}}$	$\frac{1}{\sqrt{\text{Density.}}}$	Velocity of diffusion.	Rate of effusion.
Hydrogen,	·06926	·02632	3·7994	3·83	3·618
Light carburetted hydrogen,	·559	·7476	1·3375	1·344	1·322
Carbonic oxyd,	·9678	·9837	1·0165	1·0149	1·0123
Nitrogen,	·9713	·9856	1·0147	1·0143	1·0164
Heavy carburetted hydrogen,	·978	·9889	1·0112	1·0191	1·0128
Oxygen,	1·1056	1·0515	·9510	·9487	·950
Sulphuretted hydrogen,	1·1912	1·0914	·9162	·95	
Carbonic acid,	1·52901	1·2365	·8087	·812	·821
Sulphurous acid,	2·247	1·4991	·6671	·68	

350. Mention the diffusive power of the different gases.

350*a*. **Effusion.**—The rate of effusion indicated in the last column of the table above, are results obtained by Prof. Graham, upon the rapidity with which the different gases escape into a vacuum, through a minute aperture, about $\frac{1}{300}$ of an inch in diameter, perforated in a thin sheet of metal, or of glass: it will be observed that the rates of diffusion and effusion of the different gases coincide very nearly with each other.

351. **Transpiration of gases.**—Gases pass through capillary tubes into a vacuum, according to laws similar to those observed in the case of liquids. The rate of transit for each gas, (or velocity of transpiration) is independent of its rate of diffusion. The laws observed are as follows:

1.—*The rate of transpiration for the same gas increases directly with the pressure, that is, equal volumes of air at different densities, require times inversely proportioned to their densities.*

For example: a volume of double the density of the atmosphere would pass through a capillary tube in half the time that would be required for air at its usual density.

2.—*With tubes of the same diameter, the volume transpired in equal times is inversely as the length of the tube.*

If thirty cubic inches were transpired from a tube ten feet in length, in five minutes, a similar tube, twenty feet in length, would transpire only fifteen cubic inches in the same time.

3.—*As the temperature rises, the transpiration of equal volumes becomes slower.*

Whether the tubes were of copper or of glass, or whether a porous mass of stucco was used, the same uniformity in the results was obtained.

The rate of transpiration of the different gases under the same

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350*a*. What is meant by the effusion of gases? 351. What is said of the passage of gases through capillary tubes? What is the first law of the transpiration of gases? Give an example? What is the second law? Give an example. What is the third law? What effect has the material of the tube?

circumstances, varies with the nature of the gas. It is independent of their densities or any of their known properties.

TABLE OF TRANSPIRABILITY OF GASES.

Name of gases.	Time for transpiration of equal volumes.	Velocity of transpiration.
Oxygen,	1·000	1·
Air,	·9030	1·1074
Nitrogen,	·8768	1·141
Binoxyd of nitrogen,	·8764	1·141
Carbonic oxyd,	·8737	1·144
Protoxyd of nitrogen,	·7493	1·334
Hydrochloric acid,	·7363	1·361
Carbonic acid,	·7300	1·369
Sulphurous acid,	·6500	1·538
Sulphuretted hydrogen,	·6195	1·614
Light carburetted hydrogen,	·5510	1·815
Ammonia,	·5115	1·935
Cyanogen,	·5060	1·976
Heavy carburetted hydrogen	·5051	1·980
Hydrogen,	·4370	2·228

Of all gases tried, oxygen has the slowest rate of transpiration, and hence is taken as the standard of comparison for the other gases, in the preceding table.

It is observed that a mixture of two gases, having different rates of transpirability, does not always exhibit a transpirability which is a mean of the gases when separate. With carbonic oxyd, air, oxygen and nitrogen, the rates of transpiration are in direct proportion to their densities: but these are, probably, merely coincidences, as no regular connection with the densities of the other gases can be traced.

352. **Mixture of gases with liquids.**—When a gas comes in contact with a liquid, even when there is no chemical action, the gas is absorbed in a quantity varying with the pressure to which it is subjected, and with the kind of gas. Thus the constituents of the atmosphere are always found in the water with which it is in contact.

This may be proved by the apparatus, fig. 218, consisting of a flask, *V*, furnished with a bent tube, both filled with the water to be examined. Upon boiling the water in the flask, the dissolved gas

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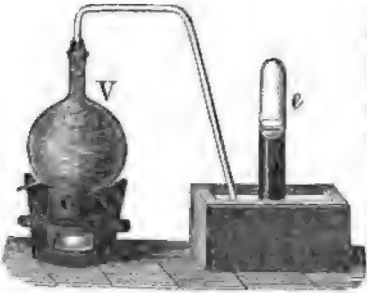
What is taken as the unit of transpirability? Give the transpirability of different gases? Is there any observed relation between the density and transpirability of a gas? 352. What is said of the mixture of gases with liquids?

separates, and is collected in the graduated tube, *e*, filled with mercury. By the analysis of the collected gaseous mixture, the proportion is found in which each of the gases existed in the liquid which has been operated upon.

218



Experiment has demonstrated that the mixture of gases with liquids is in accordance with the three following laws.

1.—*For the same gas, the same liquid, and the same temperature, the weight of the gas absorbed is proportional to the pressure; that is, that at all pressures the volume dissolved is the same.*

2.—*The quantity of gas absorbed is greater as the temperature is lower.*

3.—*The quantity of gas which a liquid will dissolve, is independent of the quantity and nature of the other gases it holds in solution.*

Thus, if instead of two elastic fluids, the atmosphere was composed of many, each would be absorbed as if it were alone, keeping in account the pressure which is proper to it. Thus oxygen, forming one-fifth of the atmosphere, water, under ordinary conditions, absorbs precisely as much oxygen as if the atmosphere were entirely composed of this gas, sustaining a pressure equal to one-fifth that of the atmosphere.

358. **Absorption of gases by solid bodies.**—Most porous solid bodies possess the property of absorbing many times their volume of gases without any chemical action taking place. The condensed gases have always a much greater elasticity than the atmosphere, always being disengaged when the temperature is raised. The absorption of different gases by charcoal, has already been noticed. (307.)

According to M. Döbereiner, platinum, in a state of extreme di-

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358. What is said of the absorption of gases by solid bodies? What is said of the absorption of oxygen by platinum? What is the force with which the oxygen in this case is condensed?

vision, (platinum sponge,) as also iridium, absorb from 200 to 250 times their volume of oxygen, without combining chemically with it, and as oxygen forms but one-fifth part of the atmosphere, they are condensed with a force equal to 1000 or 1250 atmospheres. M. M. Saussure and Döbereiner, discovered that the gases condensed in porous bodies, acquired new chemical properties, and M. M. Thenard and Dulong, have demonstrated that the property; possessed by spongy platinum is due to its porosity; for thin sheets of metal, packed closely together, pulverized or crushed glass, or porcelain, produced the same phenomena, though not to the same extent.

354. **Hydrogen lamp.**—The absorption of hydrogen by platinum sponge, is accompanied with such an elevation of temperature, that the metal becomes incandescent. The hydrogen lamp invented by Döbereiner depends on this fact; one of the most convenient forms of this apparatus is seen in fig. 219.

It consists of a vessel containing water mixed with sulphuric acid, and having suspended from its cover a glass cylinder, connected with the stop-cock, *R*. Within the cylinder is suspended a mass of zinc. Supposing *R* to be closed, and the zinc and water in contact, hydrogen is generated, which, as it accumulates, displaces the water until the zinc is not touched by the liquid; the evolution of hydrogen then ceases. If we now open *R* by pressing upon the lever *c*, a jet of hydrogen escapes by the aperture *o*, and is directed upon a mass of platinum sponge placed in *P*, which becoming red, inflames the hydrogen. At the same time that *R* is opened by pressing upon *c*, a small lamp, *L*, is moved forward, and its wick coming in contact with the ignited jet of hydrogen, is inflamed. When we cease to press on *c*, the stop-cock closes, and the lamp returns to its original position by means of a spring and rack movement. If the platinum loses its property of inflaming hydrogen, it may be restored by heating it to redness in a hydrogen flame.

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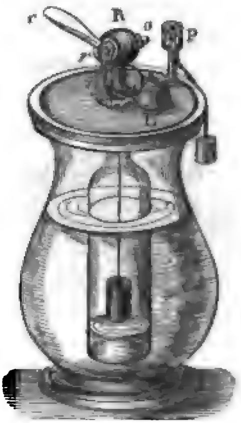
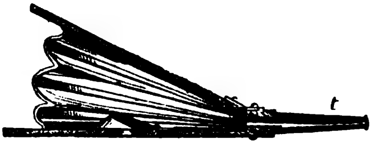


To what is this absorptive power of platinum due? 354. What is said of the effect of the absorption of hydrogen by platinum sponge? Describe Döbereiner's hydrogen lamp?

355. **Bellows.**—The most common instrument for producing a current of air is the ordinary bellows, fig. 220, consisting of two leaves of wood united by leather, and having at their smaller extremity a tube of metal; a valve is placed in the lower leaf, opening upwards.

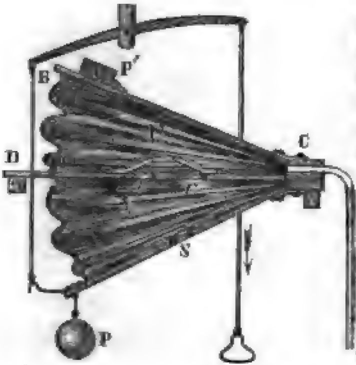
When the leaves are pressed together, the valve *s* closes, and the contained air escapes through *t*. But when the leaves are separated, air rushes in through the valve and also through the tube, through which last it is ejected upon pressing the leaves together.

220



356. **Bellows with a continuous blast.**—In the ordinary bellows, the blast of air is intermittent. Where a continuous jet is wanted, as at a smith's forge, a double blast bellows is used, fig. 221.

221



This consists of three pieces of wood, of which one, *D*, is immovable, the others are connected with this by means of leather. The apparatus is divided into two compartments, *U V*, the blast-pipe communicates with the one above; in the lower one, air is introduced through the lower valve, *S*. When the lever is drawn down, as shown by the arrow, the valve, *S*, closes, and the air being compressed, passes into *U* through the valves *r r*, raising *C B*, and partially escaping through the tube. With the reverse motion, (accelerated by the weight *P*,) the valves *r r* close, and the exterior air enters *V* by the valve *S*. During this time, the upper weight, *P′*, causes *C B* to descend, and thus there is continually an escape of air by the blast-pipe. The weight may be replaced by a spring.

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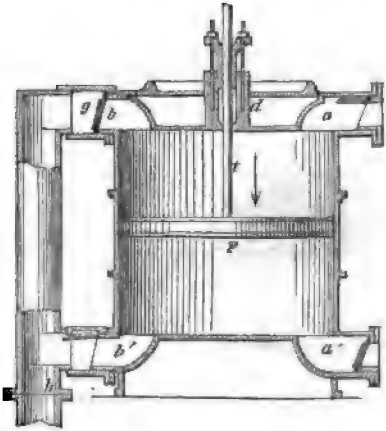
355. Describe the ordinary bellows. 356. What is the construction of the double bellows with a continuous blast?

357. **Furnace blowers.**—In great forges, and in furnaces, blowing machines are employed, by means of which a large volume of air is forced into the fire; these machines are of very various construction.

Fig. 222 represents one of them; it consists of a cast iron cylinder, containing a piston, *p*, of which the rod, *t*, passes, air tight, through a packing box, *d;* there are four valves, two of which *a a'* opening inwards, draw in air; the air passes out through the valves *b b'* which open outwards. The piston is set in motion by a steam engine or water wheel; during its *descent* the valves *a* and *b'* only are opened; through the first, air is drawn in, through the second, it is expelled; during the *ascent* of the piston, the other valves *a'* and *b*, act in the same manner. The expired and compressed air is received into the tube *g h*, through which it is conveyed to the furnace.

222



358. **Escape of compressed gases.**—When a compressed gas escapes from any opening in a thin wall, the velocity of its escape depends on the difference of the interior and exterior pressures, and on the density of the gas passing out. It has been proved,

1.—*That with the same gas at the same temperature, the velocity of its flow into a vacuum is the same at any pressure.*

That is, if we had a vessel filled with air, compressed at 1, 2, 3 or 1000 atmospheres, and allowed it to escape by a small orifice, the velocity of its flow would be the same during the whole time of its discharge. But the quantity of the gas that could escape in the same time would vary, being evidently proportional to the density

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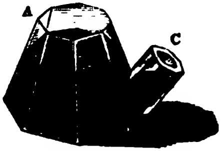
357. Describe the furnace blower represented in the figure. 358. What is said of the escape of compressed gases? What is the first law that has been proved? Give an illustration.

of the gas, that is, to the pressure. If the escape took place in a gas, as air, instead of in a vacuum, the velocity is then proportional to the difference between the elastic force of the interior and exterior air.

2.—*The velocity of the escape of gases into a vacuum is in inverse ratio to the square root of their densities.*

Where the gas escapes through long tubes instead of through orifices in a thin wall, the velocity is very much diminished, because of the friction, and is less in proportion as the tube is longer and its diameter smaller.

223



359. **Pneumatic ink bottle.**—In the pneumatic ink bottle, fig. 223, the ink in the tube *c* is kept constantly at nearly the same level. By inclining the bottle it may be filled as seen in *A*. The ink in *A* tends to force itself in the tube *C*, but is opposed by the atmospheric pressure, which is much greater than the pressure of the column of ink in *A*. As the ink in *C* is consumed, its surface, falling, will allow a small bubble of air to enter *A*, where it will exert an elastic pressure, and cause the ink in *C* to rise a little higher. This effect will be continually repeated until the bottle is emptied of ink. Bird-cage fountains are constructed on a similar principle.

360. **The syphon.**—The syphon used for decanting liquids, depends for its operation on the principle of atmospheric pressure. It consists of a bent tube, *b'*, fig. 224, having one of its arms longer than the other. It may be filled by turning it over, and pouring the liquid in, or by immersing the shorter arm in a vessel of water, and applying the mouth at *b'*; upon exhausting the air, the water will be forced up by atmospheric pressure, to supply the place of the air withdrawn, and there will then be a continual discharge until the vessel is emptied.

The two branches being filled with liquid, the pressures exerted at the points *b* and *n* will be equal, for they are on the same level; but the pressure exerted at *b'* will be greater, because of the column *n b'*, and the liquid will escape from this long branch

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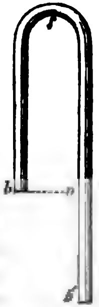
What is the second law? 359. What is the pneumatic ink bottle? 360. What is the syphon? How is it set in operation?

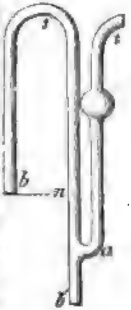
because of this excess of pressure, and will draw with it the liquid in the shorter branch; if the end of this be immersed, there will be a continual discharge as long as *b* is below the surface of the liquid, for the atmospheric pressure will cause the liquid to ascend, to supply the place of that which is passing out; otherwise there would be a vacuum produced.

224



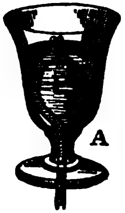
It is evident that water could not be raised by means of a syphon more than thirty-four feet: for a column of water of that height is in equilibrium with the pressure of the atmosphere. (320.) The velocity of the flow from a syphon will be the same as if the liquid fell freely from a height equal to the distance between the level of the liquid in the vessel and the end of the long arm. To avoid the necessity of filling a syphon by pouring, the form represented in fig. 225 is employed. To use this instrument, the open end, *b'*, of the longer limb is closed by the finger, while a partial vacuum, created by sucking at the small ascending tube, *t a*, occasions the liquid to pass over as in the ordinary syphon.

225



361. **Intermittent syphon. Tantalus' vase.**—Fig. 226, consists of a vessel, *A*, containing a syphon, of which one of the branches opens below the bottom of the vessel; the other is curved. When water is poured into the vessel *A*, it will rise to the same height in the interior of the tube as it attains outside. The tube will not act as a syphon until the vessel is filled to the height *n*, but when it reaches that point, the water will flow through *a*, into the long branch, filling it com-

226



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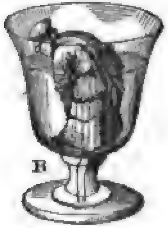
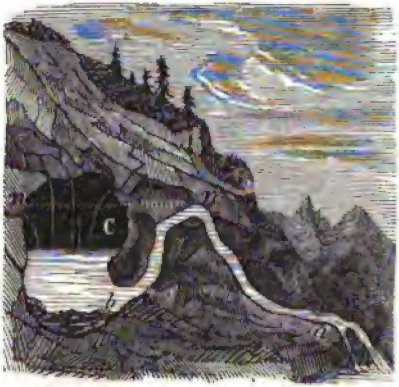


What determines and limits its operation? What is the velocity of the flow from a syphon? What is the advantage of a branch syphon?

pletely, and the syphon being now supplied, will discharge water until the vessel is emptied. The syphon may be concealed in a little image, fig. 227, *B*, representing Tantalus, so that just before the water touches his lips the syphon is filled, and the vessel is emptied.

362. **Intermittent springs.**—There exist in nature intermittent springs, the water flowing regularly for a time, and then suddenly ceasing. In these springs the opening, as at *a*, fig. 228, communicates with a subterranean cavity *C*, by means of a channel, *a n b*, which has the form of a syphon. This cavity is gradually filled, until at last the water attains the level *n n*, when the syphon is filled, and the water escapes. If the syphon discharges the water faster than it flows into *C*, after a time its level would be lowered to *b*; air would then rush in by the syphon, the flow of water would cease, and would not recommence until it had again attained the level *n n*.

228



363. **Intermittent fountain.**—The intermittent fountain consists of a vessel of glass, *C*, fig. 229, whose aperture for the admission of water is hermetically sealed by an accurately ground stopper.

A glass tube *A*, passes through the vessel *C*, its upper end terminating above the surface of the liquid; its lower end rests in a cop-

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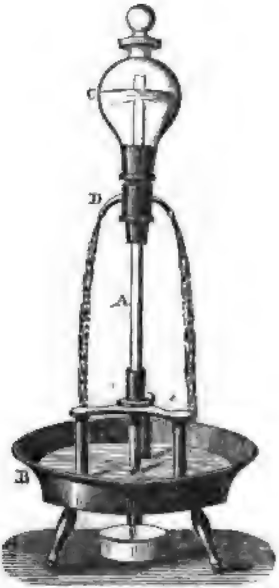
361. Describe the intermittent syphon called Tantalus' vase.
362. What is said of intermittent springs? Describe their mode of action.

per cistern, *B*, which has a small aperture for the escape of water. The globe being partially filled, the water escapes through the capillary orifices of the tube at *D*, in consequence of the atmospheric pressure transmitted through the lower end of the tube A. When the end of this tube becomes covered with water, which after a time happens, (because the orifice in the cistern *B*, does not allow so great a flow of water as can escape from the tubes at *D*,) the exterior air cannot enter the globe, and in consequence the flow ceases. The water continuing to escape from *D*, in a little time the surface is so much lowered, that the end of the tube, *A*, is out of water; the air then entering the globe, the escape recommences, and so continues at intervals until *C* is emptied of water.

229



364. **Air-pump.**—The air-pump designed to produce a vacuum in any confined space, was invented by Otto Guericke, burgomaster of Madgeburgh, in 1650. It consists essentially of a hollow cylinder of metal or glass, *A*, fig. 230, in which the piston, *B*, works air-tight. The cylinder is connected by the tube, *c c*, with the plate *E E*, on which the receiver *D* rests. A valve, *d*, opening upwards is placed in the piston, *B*. At the end of the tube *c c*, terminating in the barrel, is a second valve, *a*, also opening upwards. This valve is connected with the rod *b*, which moves air-tight through the piston, *B*. As the piston rises, this valve opens, and closes when the piston descends. By means of the stop, *F*, we may open and close communication between the receiver and the barrel of the pump, or with the external air by removing the plug *f*.

To exhaust the receiver *D* of air, the piston *B*, is raised by a lever, (not seen in the figure,) when the air, expanding, passes through the air-way whose valve, *a*, is raised with the piston, by its friction on the

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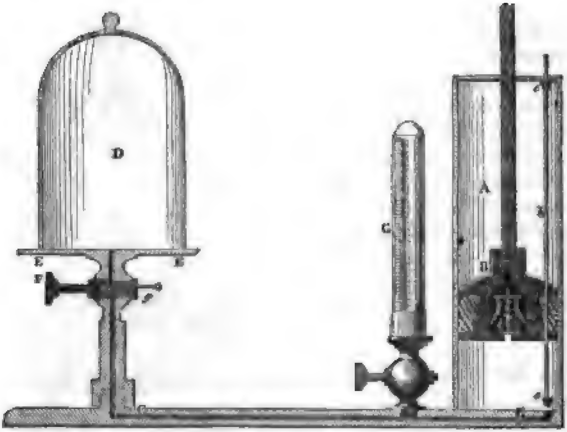
363. Describe the intermittent fountain, fig. 229. 364. Who was the inventor of the air-pump? Describe its construction.

rod *b*. The air before contained in *D*, is now diffused through the additional space in the cylinder *A*, below the piston *B*. By the descent of this piston, the valve *a* is instantly closed, and the air confined in the cylinder escapes through *d*, the valve in the piston. At each full stroke of the piston, the air in *D* thus experiences a renewed rarefaction, until at last a good vacuum is obtained.

230



The extent of the exhaustion of air is measured at every instant by a gauge. This gauge shows the difference in level which the mercury takes in the two branches of a curved tube, one end of which is closed, and the other open as in a barometer. This tube is covered by a glass cylinder *G*. When the level of the mercury in both branches of the tube is the same, the vacuum is perfect, and it is more or less incomplete as the difference in level is greater or less. From a graduated scale upon the tube, the precise amount of the exhaustion is ascertained.

An air-pump with two cylinders is often used, the pistons of which are alternately raised and depressed.

865. **Tate's double acting air-pump.**—In this pump a double piston acts in a single cylinder, and the instrument may be regarded as a single-barreled pump, capable of performimg its work with only one-half the usual motion. Fig. 231 represents

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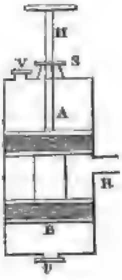
Describe its mode of action. How is the extent of the exhaustion determined?

this pump; *A* and *B* are solid pistons connected by a rod, and moved by the piston rod *A H*, which passes through the stuffing box *S;* *V* and *v* are valves opening outwards. *R* is a tube in connection with the plate of the pump.

231



On raising the pistons, the air above *A* is forced through the valve *V*, into the atmosphere, while a vacuum is being formed beneath the piston *B*. When *A* reaches the top of the cylinder, the air from the receiver rushes through the pipe *R*, into the lower part of the cylinder. In a downward stroke, the air beneath the piston *B* is propelled through the valve *V* into the atmosphere, while a vacuum is being formed above the piston *A*, and so on.

The double piston performs a double duty at every single stroke as compared with the common pump. To effect the same exhaustion, the driving power moves over only half the space, and as the exhaustion proceeds, the pressure requisite for moving the pistons, becomes less and less; the contrary is the case in the common air pump.

366. **Vacuum limited.**—It is plain, on a moment's reflection, that by mechanical means alone, it is impossible to produce a perfect vacuum. There must always remain a certain volume of air, inferior in tension to the gravity and friction of the pump valves. By employing an atmosphere of dry hydrogen to rinse out the residue of common air from an exhausted receiver, an approach to a perfect vacuum is made, inversely as the density of the two gases. Also by using carbonic acid for the same end, and absorbing the residue of this gas by dry quick-lime previously placed on the pump plate, a perfect vacuum may be produced; but by chemical and not by mechanical means.

*367. **Pneumatic experiments.**—Very numerous and instructive experiments may be made by means of a good air-pump and its accessory apparatus, a full account of which would occupy too much of our limited space. The catalogues of the leading instrument makers will be found to contain all needful details for the successful performance of these experiments. The principles involved have been already sufficiently explained.

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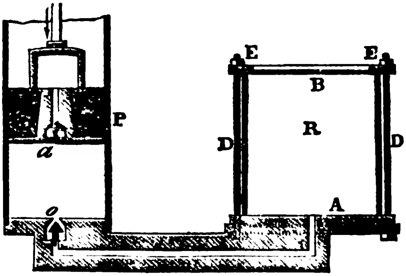
365. What is said of Tate's air-pump? How is the piston constructed? What is the position of the valves? Describe the operation of this pump. 366. Why is the vacuum limited? How is a perfect vacuum possible?

868. **Compressing machine.**—This machine is used to compress the air or any other gas; it is constructed like the air-pump, the only difference being that its valves open in a contrary direction, viz: downwards.

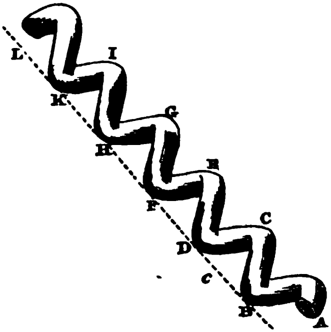
Fig. 232 represents a longitudinal section of one form of this apparatus. When the piston, *P*, is lowered, the air is compressed, and passes into the receiver, *D B D*; when the piston is raised, the valve *a* is opened by the exterior air which rushes into the barrel of the pump, while the compressed air in the receiver closes the valve, *o*. It is evident, that by every stroke of the piston, as much air as fills the cylinder is driven into the receiver, *R*, which becomes therefore filled with an atmosphere proportionally more dense than the external air.

232



869. **Archimedes' screw.**—The Archimedes' screw, is a machine said to have been invented by Archimedes in Egypt to aid the inhabitants in clearing the land from the periodical overflowings of the Nile. The instrument varies in its form, according to the manner and purposes of its application. To render the principle upon which it works intelligible, let us suppose a tube bent in the form of a cork-screw and inclined in the manner shown in fig. 233.

233



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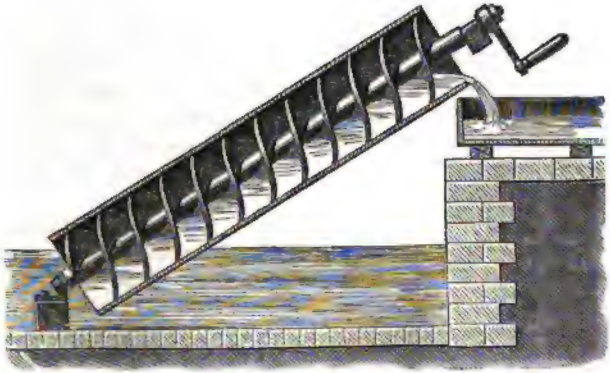
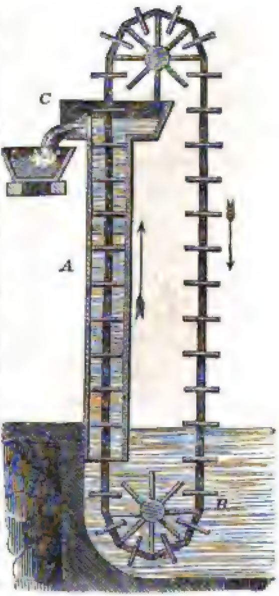
868. What is said of the compressing machine? 869. What is Archimedes' screw? Describe the principle upon which it works.

234



If a ball be placed in *A*, it will fall to *B*, and there remain at rest; if the screw be now turned so that the mouth *A*, is placed in its lowest position, the point *B*, during such a motion, will ascend, and will assume the highest position it can have. The ball will then fall to *C*; by continuing the revolution of the screw, the ball will ascend in the tube, and finally will be discharged from the upper mouth. The same would happen with a portion of liquid. If the lower extremity of the screw was immersed in a reservoir of liquid, it would gradually be carried along the spiral as the screw was turned, to any height to which the screw might extend. In practice, the screw is more commonly formed of a cylinder, to the walls of which is attached a spiral thread, as shown in fig. 231. Besides liquids, these machines are used for elevating ores in mines, or grain in breweries, &c. They are commonly used at an inclination of about 45°, but may be used at 60°; revolving 100 to 200 times a minute.

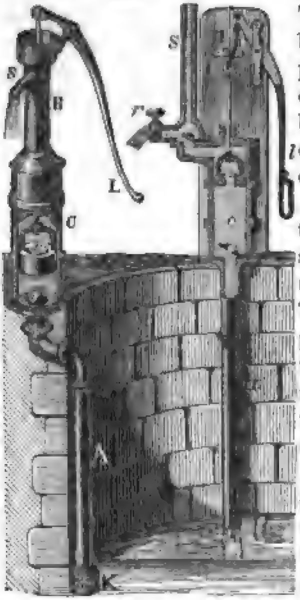
235



What is the usual form given to this machine in practice? For what are they used? What is the angle at which they are placed?

370. **Chain pump.**—The chain pump consists of a cylinder, fig. 235, whose lower end is immersed in the water of the reservoir *B*, and whose upper part enters into the bottom of a cistern, *C*, into which the water is to be raised. An endless chain is carried around the wheels above and below, and is furnished at equal distances, with circular plates, which fit closely into the cylinder. As the wheel is revolved by means of power usually applied by a winch, the circular plates successively enter the cylinder and carry the water up before them into the cistern, from which it passes out by a spout.

236



371. **Pumps.**—Pumps are designed to elevate water and other liquids above their former level. They are of various construction, but raise the liquid by the atmospheric pressure, by direct pressure, or by the effect of the two combined. They are commonly called either suction, or forcing pumps, or both united.

372. **Suction pumps.**—The suction pump, fig. 236, is composed of a tube, *A*, whose lower end is immersed in the water to be elevated. This is attached to the body of the pump, *C*, which contains a piston furnished with a valve, *r*, opening upward. The upper extremity of the tube *A*, also contains a valve, *o*, opening in the same direction. When the piston is elevated from the lower part of the pump by working the handle, *L*, the valve *r*, closes, and a partial vacuum is produced, but the elastic force of the air in *A*, causes the valve *o*, to open, and part of the air thus passes into *C*. The air in the tube is thus rarefied, and the water rushes up to such a height,

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370. Describe the construction and mode of operation of the chain pump. 371. What is said of water pumps? 372. Describe the suction pump and its operation. Why cannot water be raised in such a pump more than thirty-four feet?

that the weight of the column of water raised, added to the elasticity of the interior air, keep it in equilibrium with the atmospheric pressure. When the piston descends, the valve *o* closes by its weight, and prevents the return of the air from the body of the pump, *C*, into the tube *A*. The compressed air opens the valve *r*, and thus escapes into the atmosphere through *B*. After a number of strokes of the piston, fewer as the capacity of the tube *a* is less, the water will be elevated above the lower valve; now when the piston is lowered, the valve *r* will open and the water pass above it. Upon elevating the piston, *r* closes, and the water is raised in *B*, and escapes through the spout *S*.

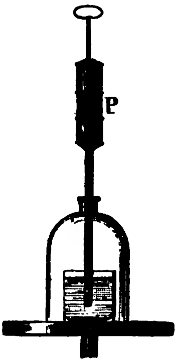
As in this and the following pump, the air is elevated to the top of the tube by means of atmospheric pressure, it is evident, that even in the most perfectly constructed pumps, the distance from the level of the water to the top of the pump, must not exceed thirty-four feet, (320,) but those of ordinary construction contain defects, so that generally we do not gain a greater height than twenty-six or twenty-eight feet. But after the water has passed over the piston, the height to which we may elevate it, is limited only by the power applied at the piston; for it is the ascensional force of this which elevates the water.

373. **Suction and lifting pump.**—Sometimes the water raised above the piston, instead of passing upwards in the tube in which the piston works, rises by a lateral ascensional tube *S*, furnished with a valve, which prevents the return of the water, as shown in *a r S*, fig. 236.

That the rising of the water in the tube is due to the atmospheric pressure, may be demonstrated by the apparatus, fig. 237. After forming a vacuum in the reservoir which contains the vessel of water, the liquid will not rise in the tube when the piston in the pump, *P*, is raised, but upon admitting the air it is rapidly elevated, as usual.

374. **Forcing pump.**—In the forcing pump, the piston has no valve. The lower part of the

237



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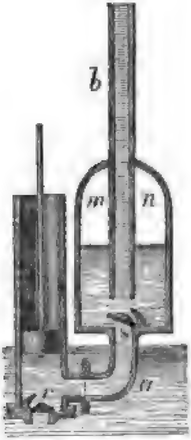
373. What is said of the suction and lifting pump? How may it be demonstrated that the rise of water is due to atmospheric pressure?

cylinder in which it works is placed in the water to be elevated, so that the valve *r*, fig. 238, which opens upward, is always immersed. The ascending tube *a b*, contains a valve, *S*, also opening upwards, and an air chamber, *m n*.

238

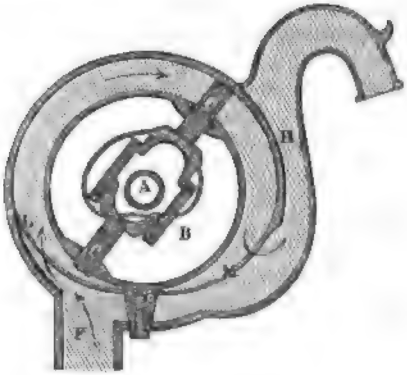


When the piston is raised, *S* is closed, and water is introduced by the open valve *r*; upon the descent of the piston, *r* closes, and the water is forced into the ascending tube *a b*. The reservoir, *m n*, filled with air, is designed to render the jet of vapor continuous. When the water is forced by the piston into the tube, the air is compressed in *m n*; re-acting afterwards by its elasticity, it continues to drive the water into the upper part of the tube, after *S* is closed, and while the piston is rising.

It is found necessary to have the air-chamber twenty-three times the capacity of the body of the pump, in order to render the jet continuous.

875. **Rotary pump.**—The rotary pump is a mechanical contrivance for raising water by a continuous rotary movement. Fig. 239 represents one of

239



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874. What is the construction of the forcing pump? What is the use of the air reservoir? What must be the capacity of the air-chamber in order to work effectively? 875. Describe the rotary pump, fig. 239. What is the mode of its operation?

the most successful of these, (Cary's.) Within a fixed cylinder is included a movable drum, *B*, attached to the axis, *A*, and moving with it. The heart-shaped cam surrounding *A*, is immovable. The revolution of *B*, causes the plates or pistons *c c* to move in and out, in obedience to the form of the cam. The water enters and is removed from the chamber through the ports or valves, *L* and *M;* the directions are indicated by the arrows.

The cam is so placed that each valve is in succession forced back into its seat when opposite *E*, while at the same time the other valve is driven fully into the cavity of the chamber; thus forcing before it the water already there, into the exit pipe *H*, and drawing after it, through the suction pipe *F*, the stream of supply. When the pump is set in action, the suction pipe is gradually exhausted of air, in which, consequently, the water ascends, and being drawn into the cylinder, it is carried around by the plates *c c*, in the manner just described.

This is the form of pump often employed in the steam fire-engines which are now coming into use.

376. **Fire-engine.**—In order to obtain a continuous and powerful jet of water from fire engines, they are usually constructed with two forcing pumps, which are alternately discharging water into a common air chamber. The pistons are moved by brakes, having an oscillating motion. The water from both pumps, forced into the air chamber, escapes through a long leathern hose, terminated by a metal tube, which serves to direct the jet.

377. **Hiero's fountain.**—In this apparatus we also obtain a jet of water by means of compressed air, produced in this case by a column of water. A common form of this apparatus is represented by fig. 240.

It consists of a metallic cistern and two globes of glass. The cistern, *D*, communicates with the lower part of the globe *N*, by the tube *B;* a second tube, *A*, joins the globes, ending in the upper part of both; *M* is partially filled with water; and lastly, a third tube passes through the cistern, and terminates at the bottom of *M*. The upper extremity of this tube has a small orifice, from which the jet of water issues.

Upon pouring water into the cistern, *D*, the liquid descends to *N*, by the tube *B*, consequently the water in the lower globe,

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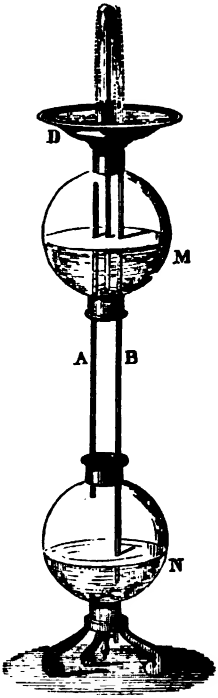
376. What is said of fire-engines? 377. What is said of Hiero's fountain? Describe the fig. 240. What is the mode of its operation?

N, supports, besides the atmospheric pressure, the pressure of the column of water in the tube. This pressure is transmitted to the air in the globe, *M*, which, reacting on the water, forces it out through the jet, as seen in the figure. If there was no friction, and no resistance from the air, the water would spout to a height equal to the difference in level of the water in the two globes.

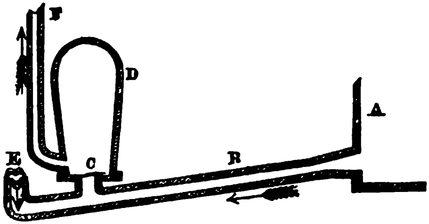
240



378. **Hydraulic ram.**—In the hydraulic ram, the momentum of a part of the fluid in motion, is effective in raising another portion. A simple form of this apparatus is seen in fig. 241. The water descends from the spring or brook, *A* ,through the pipe B, near the end of which is an air chamber, *D*, and rising main, *F*. The orifice at the extreme end of *B*, is opened and closed by a valve, *E*, opening downwards.

When the valve *E* is open, the water flows through *B*, until the current becomes sufficiently rapid to raise the valve *E*, and thus to close the orifice. The water in *B* having its motion thus suddenly checked, exerts a great pressure, and having raised the valve *C*, will rush into the air vessel *D*, where it compresses the air. The compressed air in *D*, because of its elasticity, causes the water to rise in the pipe *F*, until the water in *A B*, is

241



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378. What is said of the hydraulic ram? Describe its construction.

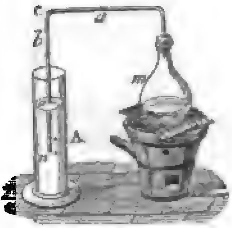
brought to rest. When this takes place, the pressure is again insufficient to sustain the weight of the valve *E*, which opens, (descends,) the water in *B* is again put in motion, and the same series of effects ensue as have already been described.

The hydraulic ram, when well constructed, is capable of utilizing about 60 per cent. of the moving power.

379. **Safety tubes.**—Chemical apparatus is often supplied with "safety tubes," in order to avoid explosions, and to prevent the mixing of the liquids contained in the different vessels of the apparatus.

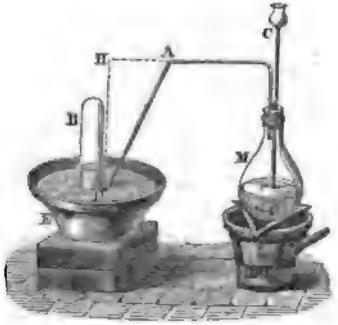
Supposing that from the flask *m*, fig. 242, a gas was disengaged, whic hpassed, by means of the tube *a b*, into a vessel, *A*, containing water, to absorb the gas. Upon withdrawing the heat, the gas in the flask would have a less elastic force, and the liquid in *A* would thus rise in the tube and pass over into *m*, destroying the process and often breaking the vessel. To avoid this inconvenience, safety tubes are used. The simplest consists of a straight tube, *C O*, fig. 243, passing through the cork, and dipping into the liquid in the flask, a short distance below the surface.

242



When the tension of the gas in M, diminishes, the atmospheric pressure exerted on the surface of the liquid in *E*, will cause a portion to rise in *D A*, and depress that contained in *C*, so that air enters, and the equilibrium is restored. Again, if more gas is generated than can escape through the exit tube *A D*, the tube *C* prevents the bursting of the flask, for the liquid escapes by the tube until the aperture *o*, is open, when the excess of gas escapes. The hydrostatic pressure exerted upon the flask *M*, is measured by the height of the vertical column *HO*.

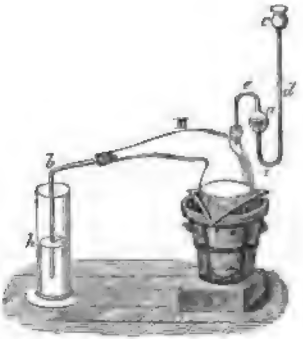
243



What is the mode of operation? 379. What are safety tubes? What is said of fig. 242? Describe the straight safety tube, fig. 242.

Another form of safety tube, (called an *S* tube,) consists of a tube bent in the shape seen in fig. 244, having often upon it a bulb, *a*. This tube is adapted to the neck of the generating vessel, *M*; the curve is filled with water or some other liquid.

244



It is plain that if the elastic force or pressure is the same within as without, the liquid will beat the same height, *d c*, in both branches of the curve; if, however, the elastic force of the gas within the retort diminishes, the column will fall, and soon, the air passing the curve and rising through the liquid, will enter the vessel and restore the equilibrium; thus preventing the liquid in *h*, from passing into the retort. Explosions are prevented, as has already been explained, in regard to fig. 243.

THEORY OF UNDULATIONS.

880. **Origin of undulations.**—By the operation of certain forces, the different parts of all bodies are, ordinarily, held in a state of equilibrium or rest. If the molecules of a body are disturbed by any extraneous force, they will, after a certain interval, return to the state of repose. This return is effected by the particles approaching the position of equilibrium, and receding from it, alternately, until at length the body, by the resistance of the medium in which it is placed, and by other causes, is gradually brought to rest. The alternate movements thus produced, are variously expressed by the terms vibrations, oscillations, waves or undulations, according to the state or form of the body in which such movements occur, and the character of the motions which are produced.

881. **Progressive undulations.**—Undulatory movements are of two kinds, progressive and stationary. In progressive undula-

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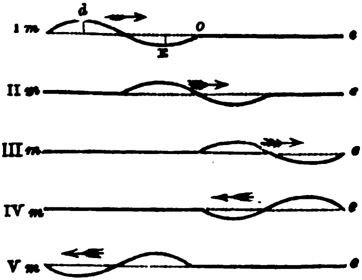
What is said of the *S* safety tube, fig. 244? Describe the mode of its operation. 380. What is the effect when the molecules of a body are disturbed by any extraneous force? How is the return of the bodies to the position of equilibrium effected? What are the alternate movements called?

tions, the particles which have been immediately excited by the disturbing cause, communicate their motion to the particles next them, and as this movement of the particles is successive, the position they assume at any particular moment during their motion, appears to advance from one place to another.

This kind of undulation is observed in a cord made fast at one end, while the other is smartly shaken up and down; the portion of the cord nearest the hand will assume the position in fig. 245, I, *m d E O*. Such a wave does not continue stationary; the moment it is formed, it advances toward the other extremity of the cord, II, on reaching which, III, an inverted curve is produced, IV, and the wave returns, V, to the position from which it started, the relative position of the elevation and depression being reversed. This alternate movement may be repeated a number of times before the cord comes to rest. These are sometimes called waves of translation.

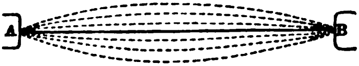
245



382. **Stationary undulations.**—Undulations are termed stationary when all parts of the body assume and complete their motion at the same time.

Thus, when a cord stretched between *A B*, fig. 246, is drawn at the middle from its rectilinear position, it ultimately recovers its original position, after performing a series of vibrations, in which all parts of the cord participate.

246



383. **Isochronous vibrations.**—Those vibrations that perform their journey on either side of their normal position in equal times, are termed isochronous, (from *isos*, equal, and *chronos*, time.)

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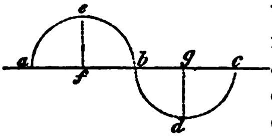
381. What is said of progressive undulations? How may these motions be produced? Describe the fig. 245. What else are such waves called? 382. What are stationary undulations?

The movements of a pendulum furnish a perfect illustration of such vibrations. (161.)

384. **Phases of undulations.**—In every complete oscillation, or perfect wave, the following parts may be recognized. The curve *a e b d c*, fig. 247, is called a wave. The part *a e b*, which rises above the position of equilibrium, is called the phase of elevation of the wave, *e* being the point of greatest elevation; the curve *b d c*, is called the phase of depression of the wave, the point *d*, being that of greatest depression. The distance of the highest point *e f*, above the position of equilibrium is called the height of the wave, and in like manner the distance *g d*, of the lowest point below the position of equilibrium, is called the depth of the wave. The distance, *a c*, between the beginning of the elevation and end of the depression, is called the length of the wave, the distance, *a b*, the length of the elevation, and *b c*, that of depression.

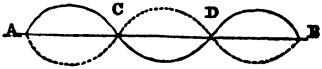
247



385. **Nodal points.**—When a body, as a string, is made to assume a series of stationary vibrations, the points where the phases of elevation and depression intersect, are always at rest.

Let the cord stretched between *A B*, fig. 248, be temporarily fixed at the points *C* and *D*, and the three parts be drawn at the same moment equally in contrary directions, so that the cord will assume the undulating form represented in the figure; if now the fixed points at *C* and *D* be removed, no change will take place in the vibratory motion of the cord; but as it continues to vibrate, the points *C* and *D*, although free, will be in a state of rest.

248



Pieces of paper resting upon these points will be undisturbed, while, if placed on the intermediate positions, they would be thrown off immediately. These are called nodal points. (Latin, *nodus*, a knot.)

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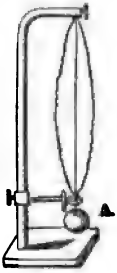
383. What are isochronous vibrations? Give an example. 384. Mention the different phases of a wave in fig. 247. 385. What points are always at rest in a series of stationary vibrations? How may this be shown?

Vibration of Solids.

386. **Solid bodies.**—All solid bodies exhibit the phenomena of vibration in various forms and degrees, varying in an infinite variety of ways, according to the form of the body, and the manner in which the force producing the vibration is applied.

387. **Forms of vibration.**—Bodies of a linear form, as tense strings, fine wire, &c., are susceptible of three kinds of vibration, which are called (1st) the transverse, (2d) the longitudinal and (3d) the torsional vibrations. A simple apparatus to exhibit these effects experimentally, contrived by Prof. August, is represented in fig. 249. It consists of a spirally twisted wire, stretched from a frame by a weight. If the weight be raised to *A*, and then let fall, it will advance and recede from its normal position, the wire performing a series of *longitudinal vibrations.*

249

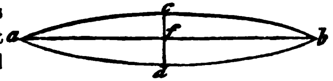


Transverse vibrations are produced by confining the lower end of the wire by a clamp. The wire is then drawn from its position of equilibrium and suddenly let go. The vibrations which it then makes, shown by the dotted lines, are transverse to the axis of the wire. *Torsional vibrations* are produced by turning the weight around its vertical axis; upon letting go, the torsion, or twist of the wire, causes it to turn back, its inertia carrying it beyond its position of equilibrium, until arrested by the resistance of the wire, and these alternate twistings will continue with a constantly decreasing energy, until gravity, and the molecular forces of the solid, restore the equilibrium.

388. **Vibration of cords.**—Cords and wires, as is familiarly seen in stringed instruments, have their elasticity developed by tension. The transverse vibrations of a body are well illustrated by the simple apparatus annexed.

Thus if the cord *a f b*, fig. 250, be drawn out in the middle to *a c b*, upon being let go, its elasticity causes it to return to its former position. This movement is effected with an accelerated

250



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386. What is said of solid bodies? 387. What three kinds of vibration are linear forms susceptible of? Describe Prof. August's apparatus. How may longitudinal vibrations be shown with it? How transverse vibrations? How torsional vibrations?

velocity, and is at its maximum when the cord has reached the line of equilibrium *a f b*, consequently it passes with a constantly decreasing velocity to *a d b*, where its motion is nothing; it then returns to *a f b*, and so continues.

One complete movement, (as from *a c b* to *a d b*,) is termed an oscillation or vibration, and the time occupied in performing it is called the time of oscillation. The vibrations of tense strings are isochronous.

389. **Laws of the vibration of cords.**—Calculation and experiment have demonstrated, that the vibration of cords is in accordance with the four following laws.

1.—*The tension being the same, the number of vibrations of a cord is in inverse ratio to its length.*

That is, if an extended cord, as of a violin, makes in a certain time a number of vibrations, represented by 1, then, in order to make a number of vibrations, represented respectively by 2, 3, 4, the cord must be ½, ⅓, ¼ as long.

2.—*The tension being the same, the number of vibrations in cords of the same material, is in the inverse ratio of their thickness or diameter.*

That is, if we take two cords or wires of the same length, of copper or steel, as those of a piano, one of which is twice the diameter of the other, and which vibrate equal lengths, the small one will make, in the same time, twice as many vibrations as the larger.

3.—*The number of vibrations of a cord is proportional to the square root of the weight it carries.*

That is, if we represent by 1 the number of vibrations made by a cord, extended by a weight of 1, then the number of vibrations made by a similar cord of the same length, in the same time, becomes respectively 2, 3, 4, &c. when the weight is increased, to 4, 9, 16, &c. Thus, if we would cause a given cord, as of a violin, to vibrate with a four-fold velocity, it is necessary to strain it to sixteen-fold the original tension.

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388. What is said of the vibration of cords? What is the complete movement called? What is the time of oscillation? 389. What is the 1st law of the vibration of cords? Give an example. What the 2d, 3d, and 4th laws? Give illustrations.

4.—*All other things being equal, the number of vibrations of a cord is inversely proportional to the square root of its density.*

Thus, if we take a cord of copper which has a density of 9, and one of cat-gut, whose density is about 1, the number of vibrations of the last in the same time will be three times that of the former.

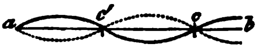
It is evident that these laws apply only to homogeneous cords, and not to those cords which are covered with another material, as a harp string of cat-gut, covered with metallic wire.

890. **Vibrations of rods.**—Rods, like cords, vibrate both in longitudinal and transverse directions. If they are fixed firmly by one of their extremities, as in a vice, they will give, when set in motion, a series of isochronous vibrations.

Elastic rods may, like strings, be divided by stationary undulations into several vibrating parts. The nodal points may be ascertained by placing upon the rods light rings of paper; these will be thrown off as long as they rest upon any point except a node, but when they reach a node, they will remain there unmoved.

The space between the free extremity and the first nodal point, is equal to half the length contained between two nodal points, but it vibrates with the same velocity. Thus *a*, fig. 251, being the fixed, and *b* the free end, the part between *b* and *c* is half the distance *c c'*. The nodal points may be rendered sensible by sand strewn upon the horizontal surface of the vibrating rod; the sand is seen to move to certain points, where it remains stationary; these are the nodes.

251



Rods may also, like cords, vibrate longitudinally, and the nodal points are formed in the same manner. It has been observed in elastic rods of the same nature, that the number of longitudinal vibrations is the inverse ratio of their length, whatever may be their diameter and the form of their transverse section.

A prismatic bar, vibrating longitudinally, undergoes a very considerable increase of length, which, in the state of repose,

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890. What is said of the vibration of rods when confined at one extremity? What is said of nodal points in vibrating rods? How may the nodal points be rendered sensible? What is said of the longitudinal vibration of rods? What of the number of torsional vibrations?

could not be produced except by a very strong tension, while the vibratory movement is obtained by a very feeble force.

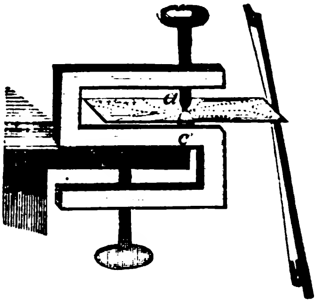
The number of vibrations by torsion in rods, is in the inverse ratio of their length, and is proportional to their thickness, the substance in all cases remaining the same.

391. **Paths of vibration.**—The motion performed by vibrating rods is often very complex. This may be beautifully seen by the contrivance of Prof. Wheatstone, consisting of a polished bead fastened on the extremity of an elastic rod, as of a knitting-needle, firmly fixed in a board or vice.

Upon making the rod vibrate, the bead, by reflection, will produce a continuous line of light. It will be seen that the arc described is not circular, but the rod appears to be impressed at the same time with two vibratory movements, at right angles to each other, and moves in a curve produced by a composition of these forces.

392. **Vibration of elastic plates.**—Vibrations are readily excited in elastic plates by the friction of a violin-bow or by blows. The plate may be confined either at its centre, or from one corner in the vice, fig. 252, resting upon a cone of cork, *c*, and pressed by the screw *a*, tipped with cork.

252



In the vibration of plates, nodal lines will be formed, which do not participate in the movements of the plane, but remain in a state of rest.

393. **Nodal lines.**—These nodal lines answer to the nodal points in linear vibrations, and if we suppose the plane to be made up of a series of rods, these lines will answer to their nodal points. They run in various directions across the vibrating surface, the contiguous ones moving in contrary directions, dividing the planes into numerous portions in opposite phases of vibration.

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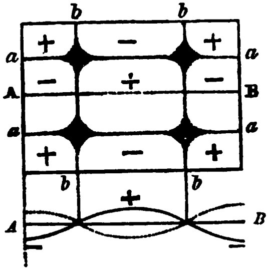
391. What is said of the paths of vibrating rods? How is this shown by Prof. Wheatstone's contrivance? 392. How may vibrations be excited in elastic plates? 393. What is said of nodal lines?

This is shown in fig. 253, by the signs + and —, *A B* being the vibrating plane. The dimensions of these internodes, (vibrating portions,) are regulated in the same manner as those of vibrating rods. The outside ones, *a b*, *a b*, are always half the size of those in the interior. The nodal lines vary in their number and position, according to the form of the plates, their elasticity, the number of vibrations, the mode of vibrating, &c.

253



394. Determination of the position of the nodal lines.—The position of the nodal lines may be determined by scattering sand or other fine material over the plate, and vibrating, as by means of a violin-bow drawn across the edge of the plate; the grains of sand will remain upon the points which are at rest, and which are therefore nodal points. Those which are upon vibrating portions, will be thrown aside until, after a time, they will have settled quietly down upon the nodal lines.

It is observed that if *lycopodium*, or some other very light powder, is placed upon the plates, it will accumulate on those parts which are in greatest vibration. Mr. Faraday proved that this phenomenon was due to small currents of air produced during the vibration of the plate, and which drew the powder with them; for in a vacuum, the powder of lycopodium is disposed, like sand, upon the nodal lines, and for the same reason; if the plate covered with sand is vibrated under water, the sand collects upon the most agitated portions of the plate, because of the similar currents excited in the water by the vibrations.

395. Laws of the vibration of planes.—Observation has determined that the vibration of planes of the same substance, and having the same degree of rigidity, are subject to the following laws.

1.—*That the number of the vibrations is independent of the size of the laminae.*

2.—*It is proportional to their thickness.*

What of their position? How is this shown in fig. 253? 394. How is the position of these nodal lines determined? What is the result if a very light powder be used, or if the vibration take place in water? 395. What is the 1st law of the vibration of planes? What is the 2d law? What the 3d law?

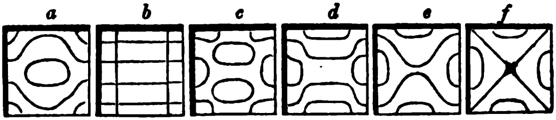
3.—*The thickness being the same, it is in inverse ratio of the square of their length.*

396. **Method of delineating nodal lines.**—As these nodal lines assume various and complicated figures, difficult to delineate with accuracy by common drawing, Savart replaced the sand by powdered litmus, previously mixed with gum water, dried and pulverized to a uniform size. The acoustic figures being produced with this powder, a paper moistened with gum water was then gently pressed upon them, thus giving an exact transfer.

This method gave great facilities for the comparison and study of these fugitive figures, so difficult to produce with perfect identity, and enabled the inventor to determine the exact limits of the nodal lines and areas of unequal vibration.

397. **Nodal figures.**—Nodal (or acoustic) figures have always a great symmetry of form, and their lines are generally as much more numerous as the number of vibrations is greater. The same plate may furnish an infinite variety of figures, which pass from one to another in a continuous manner, and not by sudden jerks. Thus the figures *a b c d e f*, fig. 254, pass into one another without intermission.

254



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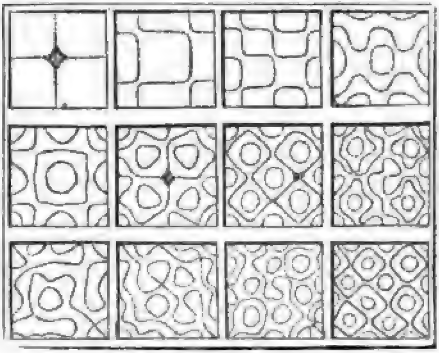

Many hundred forms of nodal figures have been figured. Fig. 255, represents a few of those obtained on square plates. Triangular and poly-

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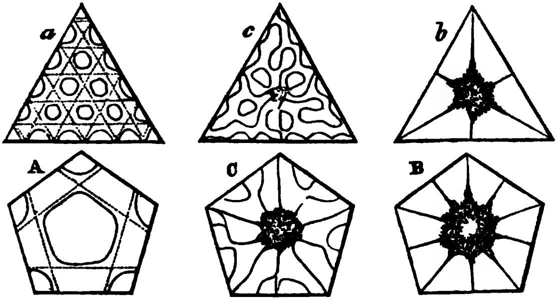
396. How may nodal lines be delineated? 397. What is said of the form of nodal figures? What of the variety of form produced on a single plate?

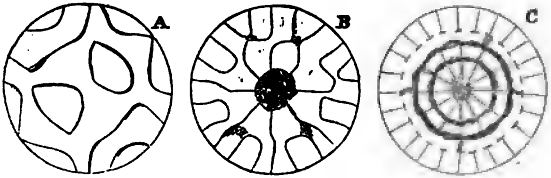
gonal plates all give symmetrical figures, analogous to those obtained with square plates, as is seen in fig. 256. With circular plates it is observed that the nodal lines distribute themselves

256



in the direction of the diameter, dividing the circle into an equal number of parts, or into more or less regular circular forms, having the centre of the plate as their common centre, or in both of these forms combined. Fig. 257 represents these different varieties of form.

257



398. **Vibration of membranes.**—The flexibility of membranes does not permit us to vibrate them unless they are stretched as in a drum. They present modes of vibration which have much analogy to those of solid plates, vibrating either by concussion, as in the drum, or by the influence of vibrations in the air. If we stretch over the top of a funnel a piece of moistened bladder, and when it is dry, suspend the apparatus by a knotted hair, passed through the centre of the membrane, we can produce symmetrical nodal lines upon its surface, strewed with sand, by passing the fingers, covered with resin, over the hair. The same

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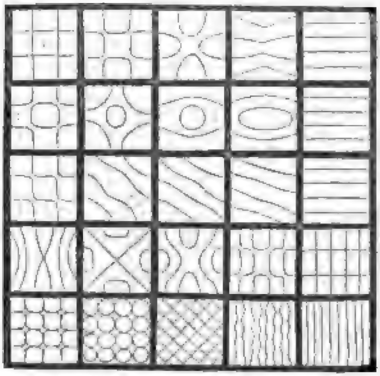
What is said of the forms on triangular and polygonal plates? What of the forms on circular plates? 398. What is said of the vibration of membranes?

phenomenon may be observed, if we bring the membrane near a bell while it is vibrating. The acoustic figures obtained by the vibration of membranes are extremely varied. Savart has observed that square membranes are divided by their nodal lines into the same forms as square plates under the same circumstances, with this difference, that the vibrating parts in the vicinity of the edges are smaller for the last, while they are equal to the others in membranes. Fig. 258 represents a few of the forms produced in the vibration of membranes. It has been found that wood and metals, in very thin laminae, vibrate like membranes.

258



Undulations of liquids.

399. **Production of waves.**—Liquids are capable of assuming undulatory movements, similar to the vibrations of solids, differing from them, however, in some respects, in consequence of the different physical arrangement of their atoms. If a depression be made at any point in the surface of a fluid in a state of rest, by the dropping in of a solid, as of a pebble into water, or by immersing and then withdrawing the solid, a circular undulation will be produced. Around the point of depression there first rises a circular elevation above the level of the liquid when in equilibrium, and immediately beyond this is a circular depression, and so, alternately, successive elevations and depressions. Thus the initial motion will be gradually propagated in a series of progressively widening circles; wave follows wave, until opposing causes

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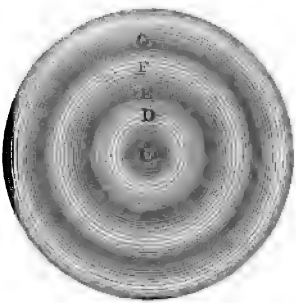
What of the forms of the nodal figures on membranes? 399. What is said of the undulations of liquids? What is the result if a pebble is dropped into water?

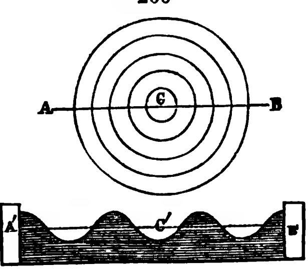
allow the equilibrium to be regained. Thus in fig. 259, the light circles *D* and *F*, represent the elevations, and the shaded ones, *C*, *E*, *G*, the depressions of these circular waves.

259



400. **Circular undulations.**—As in the case of the vibrations of solids, an entire undulation consists of a phase of depression, and another of elevation. This may be rendered more intelligible by conceiving a series of circular elevations divided at *A C B*, fig. 259, so as to present a vertical section. The phases of elevation and depression will present the series of curves shown by the line *A' C' B'*.

260



401. **Progressive undulations in liquids.**—In a movement of the kind just indicated, the fluid appears as if its entire mass advanced progressively from the point of excitation; but this is a delusion. Floating bodies, as pieces of wood, are not hurried forward on the surface of the water, but merely rise and fall, alternately, as the waves pass. The true nature of the motion is such, that each particle of the fluid describes a vertical circle, about the spot where it may happen to be, revolving in the direction in which the wave is advancing. The particle thus returns to its former position in the same plane, one half being above, and the other half below the level of the fluid. Each particle of fluid thus set in motion, imparts a similar movement to its contiguous particle, this again to the next, and so on. But as a certain time must elapse for this transmission of motion, the different particles will be describing different portions of their circular movement at the same moment. Some will be at the highest point of their vertical circle, while others are in an inter-

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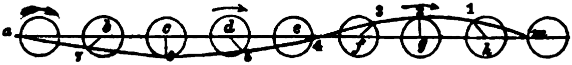
400. What is said of circular undulations? 401. What delusion is there in an undulation of the kind just mentioned? What is the true nature of the motion?

mediate position, and others at the lowest, giving rise to a wave which advances a distance equal to its whole length, while each particle performs one entire evolution.

For the sake of simplicity, we will consider only 8 of the many particles which we may conceive as occupying the horizontal surface between *a m*, fig. 261. Imagine that the particle *a* is at rest, when a descending wave strikes it. It will be depressed, and will begin to revolve in a vertical circle, its radius assuming the different positions represented in *a*, *b*, *c*, *d*, &c., during the time of one oscillation. Now if we consider eight such particles to be situated on the line *a m*, and that each particle begins its motion ⅛ of a revolution later than its neighbor next on the left hand; then at the instant when *a* has completed one entire revolution, the second will be one-eighth behind it, viz: at 7; the 3d, two-eighths behind it, viz: at 6; and the fourth, fifth, sixth, seventh, and eighth, at the points 5, 4, 3, 2, and 1 respectively, whilst the 9th particle is but just beginning to move. Connect the points *a*, 7, 6, 5 4, 3, 2, 1, *m*, and the line will represent the form of the fluid surface at that precise moment of the undulation.

261



The diameter of the circle which each particle describes, is the amplitude or intensity of the wave, *c*6, its depth, and *g*2, its height, each of which is equal to the radius of a circle which any particle describes during one oscillation. This radius is longer or shorter according to the amplitude of the wave. It is sometimes twenty feet, which makes a very high wave, probably the largest which ever occurs on the ocean in a violent storm, unless it be those waves which have increased by the accumulation of wave upon wave.

402. **Stationary waves.**—Stationary undulations may be produced by exciting waves in a circular vessel, from its central point. The waves being reflected from the circular wall, will produce another series, which, combined with the first, will produce the effect of a stationary undulation. So also they may be produced on a surface of a liquid confined in a straight channel by exciting a succession of waves, separated by equal inter-

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Explain this movement, considering eight such particles, fig. 261. What is said of the intensity of the wave? What of its height? What is said of high waves? 402. How may stationary waves be produced?

vals, moving against the side or end of the channel, and reflected from it.

403. **Depth to which waves extend.**—Waves, or undulations, are not only propagated laterally, but also in all other directions. It has been ascertained, (by the Messrs. Webber,) that the equilibrium of the liquid is not disturbed to a greater depth than about three hundred and fifty times the altitude of the wave.

404. **Reflection of waves.**—If a series of progressive waves are arrested by impinging against any solid surface, they will be reflected again from that surface under the same angle at which they struck it. This reflection of waves is occasioned by gravity, and obeys, precisely, the laws which regulate the impact of elastic bodies.

Since this law applies to all the rays which constitute the breadth of a wave, the path of a reflected wave may readily be determined by a knowledge of the surface and the angle of incidence. If the wave is linear, (that is, if the line resting upon the highest point of the elevation at right angles to the direction in which it is moving, is a straight line,) and it meets a plane surface, it will be reflected, and return in the same path. If it meet the surface at an angle of 20° or 30°, it will be reflected at the same angle, on the other side of the perpendicular to the reflecting surface.

405. **Waves propagated from the foci of an ellipse.**—If the vessel is in the form of an ellipse, and a wave originate at one of the foci, all the rays will converge so as to fall simultaneously, after reflection, on the other focus.

262

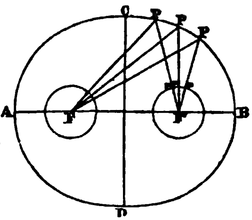

Fig. 262 represents an ellipse, of which *F*, and *F'* are the foci, which have the following property. If lines be drawn from the foci to any points, *P*, *P*, *P*, in the ellipse, these lines will form equal angles with the ellipse at *P*, and their lengths taken together, will be equal to the major axis *A B*. If we suppose a series of circular progressive waves propagated from the focus *F*, their rays will strike successively, and at equal angles upon the elliptical surface, as at the points *P P P*; they will be re-

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403. To what depth do waves extend? 404. What is said of the reflection of waves? How may the path of a reflected wave be readily determined? 405. If waves originate in one of the foci of an ellipse, how are they reflected?

flected in the direction *P F*, towards the other focus. But as all the points of the same wave move with the same velocity, they will all reach the focus *F* at the same time, for the distances they pass over are equal. Hence it follows, that each circular wave that expands around *F*, will, after it has been reflected from the surface of the ellipse, form another circular wave around *F* as a centre.

406. **Waves propagated from the focus of a parabola.**—If the surface be a parabola, and a wave originate at its focus, all the rays will, after reflection, pass in parallel lines. Or, if the rays impinge in parallel lines, they will, after reflection, converge to the focus.

Fig. 263 represents the parabolic curve. The point *V*, is its vertex, the line *V M*, its axis. The point *F*, upon the axis, is the focus, and has the following property. If lines be drawn from the focus to any points, *P*, in the curve, and other lines be drawn from the points, *P*, severally parallel to the axis *V M*, meeting lines *W W*, drawn perpendicular to the axis, the lines *F P*, and *P p*, will be inclined at equal angles to the curve at the point *P*, and the sum of their lengths will be every where the same. Hence it may be demonstrated, as in the case of the ellipse, that if a series of progressive waves be propagated from the focus *F*, these waves, after striking the curve, will be reflected, so as to form a series of parallel straight waves.

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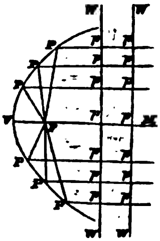

Moreover, it is evident that if two parabolas face each other, so as to have their axes coincident, a system of progressive circular waves, issuing from one focus, will be followed by a corresponding system, having for its centre the other focus. For if a series of parallel straight waves strike a parabolic surface, their reflection would form a series of circular waves, of which the centre would be the focus.

Rays reflected from spherical surfaces, whose extent is small compared with their diameter, will, in their direction, approximate closely to those reflected from a parabolic boundary.

407. **Circular waves reflected from a plane.**—If the diverging rays of a circular wave fall upon a plane surface at right angles

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Illustrate by fig. 262. 406. How are waves reflected from the focus of a parabola? Illustrate this by fig. 263. What is the effect if two parabolas face each other when a system of waves issue from the focus of one?

to it, their path, after reflection, is the same as it would have been had they originated from a point on the opposite side of the plane, and as far back as the point of origin itself; that is, the form of the reflected wave will be the reverse of the incident wave, for the rays which first strike the surface will be reflected first, and will have returned to the same distance from the surface at the time when the last rays meet it, that these last rays were at the moment when the first were reflected.

Thus, suppose the wave *g a d*, proceeding from the centre *c*, fig. 264, impinges on the plane surface, *e f*. The form of the wave, after reflection, will be the same that it would have been had it proceeded from *c'*, on the other side of *e f*, (at the same distance.) It is evident that with a circular wave, all its points cannot impinge at the same time on a plane, therefore, the advance portions will first impinge, and will first be reflected; and when *a* impinges, the rays at *d* and *g*, have still to go through the distances *d e* and *g f*, before they can be reflected; but in the space of time required for this, the ray at *a* will have returned to the point *k*. In the same way it may be shown that the intermediate rays will have returned to intermediate positions, and be found in the line *e k f*, symmetrically situated to the line *e n f*, in which they would have been had they not been reflected from the plane. And it further follows, that the centre, *c'*, of the reflected wave *d k g*, is as far from *e f*, as is the centre, *c*, of the circular wave, *e n f*, but on the opposite side of the median plane, *e a f*.

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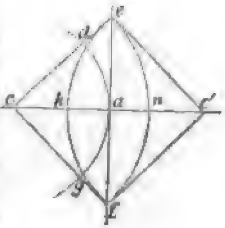

408. **Combination of waves.**—Where two systems of waves, coming from different centres, meet each other, several effects may follow, according to the mode of meeting, which curiously illustrate the principles of undulation in all departments of physics. 1st.—If the elevations of the two waves coincide, and, consequently, their depressions also, then a new wave will be formed, whose elevations and depressions will be the sum of those of the two originals. 2d.—If the two waves of equal amplitude are so superimposed that the reverse of the last case is true, *i. e.*, that the elevation of one fits the depression of the other, then

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407. What is said of circular waves reflected from a plane? Illustrate this effect by fig. 264. 408. What is said of the combination of waves in the three cases supposed? In what cases is this interference observed?

both are destroyed, and the surface is horizontal. Or, 3d, if one wave had greater amplitude than the other, then the resulting wave will have a height equal to the difference between the greater and the less.

This combination, or *interference* of waves, is of universal occurrence in all media, in which force of any kind is propagated by undulations.

409. **Interference in an ellipse.**—The two systems of waves formed by an elliptical surface, and propagated, one directly around one of the foci, and the other formed by reflection around the other, exhibit not only the phenomena of reflection, but also of interference. These phenomena are represented in fig. 265, where *a* and *b* are the two foci. The strongly marked lines are the elevations, the more lightly traced lines are the depressions, the points where the more strongly marked circles intersect the more faintly marked circles, are points where an elevation coincides with a depression, and are therefore points of interference. The series of these points form lines of interference which are indicated in the diagram by dotted lines, which, as will be seen, arrange themselves regularly in the form of parabola and ellipses about these foci.

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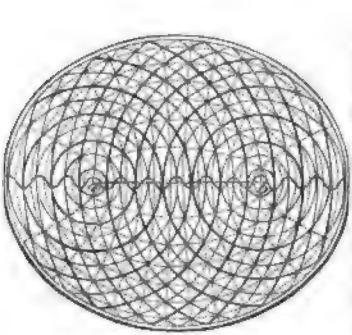

410. **Undulations of the waters of the globe.**—The undulations produced in the oceans, lakes, rivers, and other large collections of water upon the surface of the globe, are of extreme importance in the economy of nature. Did not water possess, as a consequence of the mobility of its particles among each other, the property of being thus set in motion, the ocean would soon be rendered putrid by the docomposition of the mass of organized matter it contains. The principal physical cause which produces these undu-

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409. What is said of the interference of waves in an ellipse? Describe fig. 265. 410. What is said of the undulations of the waters of the globe? What are the principal causes which produce these undulations?

lations on a moderate scale, is the motion of the atmosphere. On a large scale they are produced by the combined effects of the attraction of the sun and moon upon the surface of the ocean, which causes the ebb and flow of tides. The difference in temperature and density of the waters of different parts of the ocean, cause currents, in the efforts of these waters to assume a state of equilibrium; and lastly, the rotation of the earth upon its axis, originating the constant easterly current. A full discussion of these interesting questions belongs to Physical Geography.

Undulations of Elastic Fluids.

411. **Undulations of air.**—Undulations are produced in air or in any elastic fluid by any disturbance of their density. These undulations are due to elasticity. If any elastic fluid be compressed and again suddenly relieved from compression, it will expand, and in its expansion exceed its former volume to a certain extent; after which it will again contract, and thus oscillate alternately on either side of the position of repose. It is obvious that we must regard these undulations, or pulses of air, as extending equally in all directions in the free air, and limited only by the walls of the containing vessel or apartment when the air is confined. Therefore, the effects of the united oscillations extend equally in the course of radii, from the centre to every point of the surface of a sphere.

412. **Undulations of a sphere of air.**—The oscillations of air will not be confined to the sphere in which they commence. When air is first contracted, an aerial shell, bounding the sphere of contraction, expands, and becomes thereby less dense than when in equilibrium. Again, upon the expansion of the original sphere, the bounding shell contracts, and becomes more dense, in virtue of its inertia and elasticity. This bounding shell of air thus acts upon another, external to it; this in its turn on another, and so on, and thus the initial force is propagated upon concentric portions of air; its effects becoming less marked with each, until, like the ripple of a wave of water, it becomes too evanescent to be

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411. How are undulations produced in air? Do these undulations proceed in every direction? 412. What is said of the undulations of a sphere of air? To what is this alternate condensation and expansion analogous? What is the length of a wave in a sphere of air?

appreciated. This alternate condensation and expansion, extending spherically around the original centre of disturbance, is perfectly analogous to a series of circular waves formed around the central point upon the surface of a liquid. The elevation of the liquid in the wave, corresponding to the condensation in the case of a gas, and the depression of the wave corresponding to the expansion of the gas.

The radius of the hollow sphere, or the distance the undulation had traversed when the first particles resumed a position of rest, is called the length of a wave; the entire sphere compressed within these limits constitutes a wave, and the time of vibration is equal to the time in which motion is propagated through the entire length of a wave. If the cause which excited the undulation continues to operate, there will arise a second, and third wave, &c., within the first, and concentric with it.

This radial propagation of undulations in the air can take place with equal velocity only when the atmosphere is equally dense and elastic in all directions. If this is not the case, such a wave cannot have a spherical form.

Let *C*, fig. 266, be the point of impulse of the vibration, *C m* the distance at which the particles first excited began to return; *m n* the space which the undulations traversed before the particle *m*, had arrived against *e p*; *C a* is, therefore, the length of the wave. The same is true with regard to the points *n*, *o* and *d*, and the distance *a b*, *f d*. Now conceive the sphere of air to be intersected by a plane, passing through the point of impulse, *C*, then the circles *a e f g*, *b h i k*, *d b p q*, will be the sections of successive spheres.

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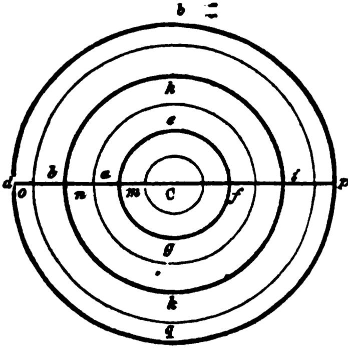

418. **Velocity and intensity of aerial waves.**—The velocity with which such undulations are propagated through the atmosphere, depends on, and varies with the elasticity of the fluid. Waves, both large and small, are transmitted with an equal velo-

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What is a necessary condition for the propagation of the undulations with equal velocity? Describe fig. 266.

city, so long as the elasticity remains the same. The intensity of vibration, *i. e.*, the dimensions of the spaces which the individual particles traverse while in this state of movement, depends on the energy of the disturbing force, which, it is also evident, is a measure of the degree of compression of the wave.

414. **Interference of waves of air.**—If two series of ærial waves coincide as to their points of greatest and least condensation, a new series of waves will be formed, whose greatest condensation and rarefaction is determined by the sum of these points, as prevailing in the separate undulations. But where the series are so arranged, that the point of greatest condensation of one, coincides with the point of greatest rarefaction in the other, the resulting series will have condensations and rarefactions equal to the difference between the waves which meet. If they are equal, total interference takes place, as in the case of non-elastic fluids, and silence results, if the waves are those of sound. (408.)

Indeed all the effects described in the case of waves formed upon the surface of a liquid, as the reflection and inflexion, are reproduced under analogous conditions in the case of undulations of æriform bodies. It must, however, be borne in mind, that these ærial waves have always a spherical form.

415. **Intensity of waves of air expanding freely.**—The undulations produced in air, form progressively increasing spheres (412,) the magnitude of whose surfaces are to each other as the square of their radii, or as the square of their distance from their respective points of impulse. As the intensity of the wave is diminished in proportion to the space over which it is diffused, it follows, that the effect or energy of these waves diminishes as the square of the distances from the centre of propagation increases. So soon, however, as the radial extension of the wave meets with any resistance which reflects the rays in a parallel or concentric direction, this rule ceases to be applicable.

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413. What is said of the velocity of ærial waves? Upon what does the intensity of vibration depend? 414. What is said of the interference of waves of air? 415. What is said of the intensity of ærial waves expanding freely?

ACOUSTICS.

Production and Propagation of Sound.

416. **Acoustics.—Sound.**—Acoustics, (derived from the Greek verb, *akouo*, to hear,) teaches the science of sounds, their cause, nature, and phenomena. Sound is the impression produced on the sense of hearing by the vibrations of sonorous bodies. Vibrations are transmitted to the ear, by the surrounding medium, which is ordinarily the atmospheric air.

417. **Sound and noise.**—Sound properly so called, or musical sound, is that which produces a continuous sensation, and of which we may appreciate the musical value; while noise, like the explosion of a cannon, is so short in duration, that it *cannot* be well appreciated; or often, it is a compound mixture of many discordant sounds, as the rolling of thunder, or the noise of waves, producing in their combination a species of harmony.

The physical difference between sound and noise is not well understood; there are ears so well organized, that they can determine the musical value even of the noise produced by a wagon rolling over the pavement. In general, all vibrations, in proportion as they are regular, uniform, and equal, produce sounds more agreeable and musical.

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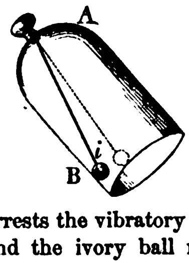

418. **All bodies which produce sound are in vibration.**—If the sonorous body is solid, and presents a large surface, as a bell jar, the vibrations may be shown by suspending a small ivory ball, *i*, by a thread in the interior of the jar *A B*, inclined in the position seen in fig. 267. When the jar resounds with a blow, the ball is thrown from the sides, as shown by the dotted line, and returning, is again thrown off, and so continues bounding, in consequence of the vibrations. A touch from the hand arrests the vibratory movement in the glass: the sound ceases, and the ivory ball remains quiet. If the sonorous body is a plane surface, its vibrations may be shown by the formation of

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416. What is the object of acoustics? 417. What is the difference between musical sound and noise? 418. How may the vibration of a sonorous solid be shown? How if the sonorous body is a plane surface?

nodal lines, (392,) with grains of sand scattered upon it. When the sound is produced by a stretched cord, the vibrations may be felt by touching the cord lightly with the hand, or may be seen by placing bands or rings of paper upon the vibrating cord, (385.) In wind instruments, it is the air which they contain, whose vibrations produce the musical sounds.

This may be proved by an organ-pipe, or by a glass tube, fig. 268, when a current of air is passed into it through the foot, *O*. A small membrane of gold beater's skin, extended on a circle of paste-board, *B*, is placed within the tube, and sustained in a horizontal position by means of a thread. Grains of sand strewed upon the membrane, will be arranged in nodal figures, proving that the membrane obeys the vibratory movement of the air which surrounds it. That the vibrations are not due to an ascending current of air, is proved by the fact, that the membrane does not vibrate when it is placed midway of the length of the tube, [a nodal point,] but above or below this point it vibrates, and more strongly as it is further removed from the centre.

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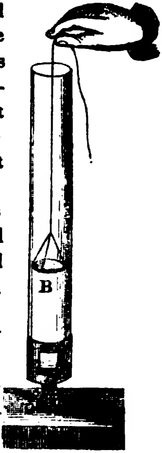

419. **Sound is not propagated in a vacuum.**—The vibrations of elastic bodies do not produce an impression on the ear, unless there exists between this organ and the sonorous body an uninterrupted elastic medium, vibrating with it. This medium is ordinarily the atmospheric air, but other gases, also vapors, liquids and solids, transmit sound.

To prove that sound is not propagated in a vacuum, place under the receiver of an air-pump, a bell, kept in constant vibration by a clock-work movement, fig. 268. The bell apparatus should be placed upon wadding, otherwise the vibrations would be communicated to the plate of the air-pump, and thus to the air. While the receiver is filled with air at the ordinary pressure, the sound is distinct; as the air is gradually exhausted, the sound grows more and more feeble, until finally, when a vacuum is obtained, it ceases to be heard, but is immediately revived by admitting air again.

When the sound is produced by a flexible cord, how may vibrations be demonstrated? How may the vibration of air contained in wind instruments be demonstrated? 419. Is sound propagated in a vacuum? How may it be proved that an elastic medium is necessary to convey sound?

420. **Sound is propagated in all elastic bodies, liquids and solids, as well as gases.**—If, in the experiment just described, the vacuum is supplied with hydrogen gas, (density 0·0692,) or any gas of less density than atmospheric air, a sound will be transmitted from the bell, very feeble for the hydrogen, and increasing as the gas is more dense. In like manner, a person whose lungs have been filled with hydrogen gas, utters only a shrill piping sound.

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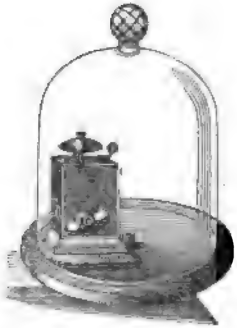

Vapors, water, and other liquids, also, like gases, transmit sounds, and with much more energy. When two bodies are struck under water, the sound is distinct. A diver on the bottom of a river hears all that is said on the shore. As to solids, their conductibility of sound is so great, that if we apply the ear to one end of a beam of wood, the slightest shock, as the scratch of a pin at the other extremity, may be heard distinctly. The noise of cannon may be heard a distance of more than two hundred and fifty miles, by applying the ear to the solid earth. In several mines in Cornwall, England, there are galleries which extend under the sea, where the sound of the waves is clearly heard when the sea is agitated, rolling the pebbles and bowlders over the rocky bottom of the ocean.

The music from a company of musicians, playing in orchestra upon numerous instruments, has been transferred to an apartment in another house, by a cord stretched across the intervening street, connecting at one end with a sounding board, and at the other extremity with a wooden box. On placing the ear at an opening in the box, the whole musical movement was heard, reproduced in miniature, being transmitted by the vibrations through the cord. At the same time a bystander in the same apartment was unconscious of there being any performance.

421. **Hearing** is a sense depending upon the ear, a beautifully constructed instrument, designed to gather in the vibrations of the surrounding air. This vibratory movement is communicated to the acoustic nerve by the aid of organs which will be described in detail at the close of this chapter.

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420. How is sound propagated in hydrogen? What is said of the transmission of sound in water and other liquids? What is said of the conductibility of sounds of solids? What remarkable fact is mentioned of certain mines in Cornwall? How has music been transferred from one apartment to another? 421. What is said of the animal ear?

422. **Velocity is the same for all sounds.**—Sound is not transmitted instantly. Experience testifies to the truth of this statement. An appreciable time elapses between the instant when we see the flash from a cannon, and that in which we hear the explosion. The velocity of sound is the space that it traverses in a second. Theory demonstrates, that the velocity of the vibrations of sonorous bodies in the same medium, is the same for all sounds, grave or sharp, strong or feeble, and whatever may be their time. Observation confirms this result, at least for those distances on which we have experimented. There is no confusion in the effects of music, at whatever distance it may be heard.

If the different notes simultaneously produced by the various instruments of an orchestra, moved with different velocities, they would be heard by a distant auditor at different moments, so that a musical performance, except to those in its immediate vicinity, would produce only discords. M. Biot, in playing an air upon a flute at the extremity of a pipe of the aqueduct of Paris, found that the sounds came to the other end, having exactly the same interval, demonstrating that the different sounds traveled with the same velocity.

423. **Velocity of sound in air.**—Numerous experiments have been made for estimating the velocity of sound; that is, the space that it travels over in a second. The most extensive and accurate system of experiments were those made in 1822, by the Board of Longitude of France, conducted by Messrs. Prony, Arago, Humboldt, Gay Lussac, and others.

Two pieces of cannon were used, one placed at Montlhéry, the other at Montmartre, between which the distance is 18·612 m., (= 61,418·6 feet,) or more than ten miles. The discharges were reciprocal, so as to avoid the influence of the wind. At each station were numerous observers, furnished with chronometers, who noticed the time between the appearance of the light, and the arrival of the sound. This time may be called that which the sound requires to pass from one station to another, for the time occupied by the passage of the light between the two points is wholly inappreciable. The mean time required to transmit the sound was 54·6 seconds. By dividing the distance between the two

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422. What shows that time is required to transmit sound? What is the velocity of sound? Are all sounds transmitted with the same velocity? What facts prove that different sounds move with the same rapidity? What was Biot's experiment? 423. Mention the experiments of the French Board of Longitude on the velocity of sound in air? What is the velocity of sound in air? What effect has temperature on the velocity of sound? What is the effect of wind?

stations by this number, the velocity, per second, is obtained. The velocity of sound at 61° F., (16° C.,) that being the temperature of the atmosphere during the experiment, is 1,118·3 feet, (340·88 m.,) for 18·612 + 54·6 = 1,118·3 +.)

It has been determined, 1.—That the velocity of sound decreases with the temperature; at 50° F., (10° C,) it is 1105·66 feet, (337 m.) So that as the temperature is lowered, sound diminishes in velocity about one foot for every degree. 2.—That at the same temperature the velocity remains the same, whether the sky is bright or cloudy, the air clear or foggy, the barometric pressure great or small, provided the air is tranquil. 3.—That its velocity varies with the velocity and direction of the wind.

424. **Newton's formula.**—Sir Isaac Newton determined the velocity of sound in air, theoretically, basing his formula upon the elasticity and temperature of the air. His results were found to be one-sixth less than those given by experiment. La Place showed, that the error resulted from the effect of the heat developed and absorbed, by the alternate compression and rarefaction of the air, in the sonorous undulations, and which Newton had neglected in his calculations. Introducing these changes of temperature into the calculation, Newton's formula gives exactly the same results as were obtained by experiment.

425. **Velocity of sound in different gases.**—The velocity of sound in the different gases, is in the inverse ratio of the square root of their densities.

Dulong has determined by calculation the velocity of sound in the following gases, at the temperature of 32° F. Carbonic acid 380·58 feet, (116 m.,) oxygen, 1,040 feet, (317 m.,) olefiant gas, 1,030·2 feet, (314 m.,) air, 1,092·54 feet, (333 m.,) carbonic oxyd, 1,105·6 feet, (337 m.,) and hydrogen, 4,163 feet, (1,269 m.,) each in a second.

426. **Calculation of distances by sound.**—The known velocity of sound per second, (1118 feet,) enables us to obtain a close approximation of the distance of the sonorous body. This follows as a consequence of the very experiments (423) by which the velocity of sound was determined. From the known laws of falling bodies, (153 *et seq.*,) we may also, with the aid of the known velocity of sound, obtain an approximate estimate of the height of a precipice, or the depth of an abyss, from the time

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424. What is said of Newton's formula for the velocity of sound? 425. What is said of the velocity of sound in gases? Mention some of the results of Dulong's calculations on this subject. 426. How may the distance of a sound often be determined?

occupied by the sound of any projectile, let fall from the hand, in reaching the ear.

427. **Velocity of sounds in liquids.**—The velocity of sounds in liquids is much greater than in air. In 1827, Messrs. Culloden and Sturm, experimenting upon the velocity of sound in the Lake of Geneva, found it to be 4,708 feet (1,435 m.) per second, or about four and a half times greater than in air.

Agitation of the water, liquids, &c., did not affect either the rapidity or intensity of the sound. But the interposition of solid bodies, such as walls, or buildings, between the sounding body and the observer, almost destroyed the transmission of sound in water; an effect which does not take place nearly to the same degree in air. (430.)

428. **Velocity of sounds in solids.**—Sound is transmitted by solid bodies with much greater rapidity than in air, but by no means with equal velocity, varying much with the elasticity and density of the different solids.

The most exact experiments have been made by M. Biot, (422,) with a series of water pipes in Paris, which had a length of 3,120 feet, (951 m.) A bell was hung at the centre of a ring of iron, fastened to the mouth of the tube, so that the vibrations of the ring would affect only the metal of the tube, and the vibrations of the bell only the included air. When the ring and bell were struck simultaneously, an observer, placed at the other end, heard two sounds; the first transmitted by the metal, the second by the air. By noticing the interval of time between the arrival of the two sounds, it was ascertained that the velocity of propagation of sound in cast iron is about 10·5 times that observed in air; that is, 11,609 feet, (3,538·5 m.) Similar experiments were made by Hassenfratz on the velocity of sound in stone, on the walls of the galleries of the catacombs which underlie Paris, by observing the interval of time between the arrival of a sound transmitted by the stones and of that transmitted by the air of the gallery.

The velocity of the propagation of sound has been determined theoretically by Savart, Chladni, Masson and Wertheim, from the number of longitudinal and transverse vibrations of the bodies, or on their co-efficient of elasticity. Chladni found, by the aid of longitudinal vibrations, that in wood, the velocity of sound is from ten to sixteen times greater than in air. In metals, the ve-

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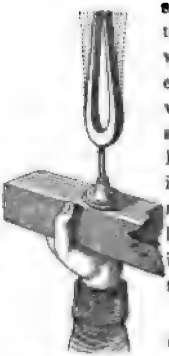
427. What is said of the velocity of sounds in liquids? What effect have interposed solid bodies? 428. What is said of the velocity of sound in solids? Mention Biot's experiment on the velocity of sound in metals and in air. What is the velocity of sound in wood? What in metals?

locity is more variable, being from four to sixteen times as great as in air.

429. **Interference of sound.**—When two series of sonorous undulations encounter each other in opposite phases of vibration, the phenomena of interference are produced. The undulations will become mutually checked, and if the two sounds are of equal intensity, instead of producing a louder sound, as might be expected, they will altogether destroy each other and produce silence. If, however, *one* of the sounds ceases, the other is immediately heard.

If two sounding bodies were placed in the foci of an ellipse, no sound would be heard, if an ear was placed on any of the lines of interference indicated by the dotted lines, (fig. 265, § 409,) but if one sound was stilled, the other would be heard, or if the ear was placed between the lines of interference, then both sounds would be heard simultaneously, and would be louder than either alone.

The interference of sounds may be shown by means of a common tuning fork.



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When in vibration, its branches recede from, and approach each other, as shown by the dotted lines in fig. 270. If the instrument, when vibrating, is placed about a foot from the ear, with the branches equi-distant, both sounds will be heard; for the waves of sound combine their effects; but as it is slowly turned around, the sound will grow more and more feeble, until at length a position will be found in which it will be inaudible. For, as the tuning fork is turned, the waves of sound interfere, and produce partial or total silence. This may also be illustrated by attaching a tuning-fork, lengthwise, to any rotating support. When the fork is vibrating, no sound will be heard so long as it continues to rotate.

430. **Acoustic shadow.**—Persons cut off from observation by a wall, or other obstacle, still hear sounds distinctly, although with a diminished volume. Thus a band of music in an adjacent house, or neighboring street, is readily followed in the softest melody. Intervening obstacles, therefore, however opaque to light, do not cast perfect shadows to

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429. When is interference of sound produced? What is the effect when two sounding bodies are placed in the foci of an ellipse? How may the interference of sound be shown by a tuning-fork? 430. What is said of acoustic shadows?

sound. The sound is not entirely cut off, because the obstacle is elastic, and propagates the vibrations it receives in a manner analogous to light passing through a transparent medium.

To a distant observer, the roar of a railway train is instantly hushed on entering a tunnel, and as suddenly renewed on its emergence.

Acoustic shadows are much more distinctly recognized when large masses, as edifices or rocks, intervene; so large as not to enter into vibration.

Although there is not complete silence in the acoustic shadow, still it is analogous to the shadow of light, for there is never complete obscurity in the latter case, even when we take the utmost precaution; still the light spreads behind the obstacles which arrest it.

431. **Refraction of sound by mixed media.**—The passage of sound is uniform and undisturbed, only when it passes through a perfectly homogeneous medium; when it passes through substances having different degrees of elasticity, the rays undergo a change of direction, (refraction takes place,) sonorous waves of various intensities are produced, which, partly by reflection, and partly by interference, become broken up into myriads of secondary vibrations.

A glass filled with carbonic acid gas, when struck, instead of giving the full tone proper to it, merely produces an irregular flat sound; the striking of a clock is less loud when covered by a glass shade; blows struck in a diving-bell immersed in water, are distinctly heard on the surface, but a sound immediately above the water will not be audible to persons within the bell. In all of these cases, the rays of sound undergo a change of direction, as do those of light and heat, in passing from one medium to another.

432. **Distance to which sound may be propagated.**—The distance at which sounds are audible, does not admit of precise measurement. In general, it may be stated, that a sound will be heard further, the greater its original intensity, and the denser the medium in which it is propagated. It also depends, greatly, on the delicacy of hearing of different individuals. The intensity of sound, like that of all forces acting in lines, diminishes in the inverse ratio of the squares of the distance of the sounding body. Thus, if the linear dimensions of a theatre be doubled,

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Why is not sound completely cut off by an interving obstacle?
431. What is said of the refraction of sound by mixed media?
432. What is said of the distance to which sounds may be propagated?

the volume of the performers' voices at any part of the circumference will be diminished in a four-fold proportion.

A powerful human voice in the open air, at the ordinary temperature, is audible at the distance of seven hundred feet. In a frosty air, undisturbed by winds or current, sound is heard at a much greater distance with surprising distinctness. Lieut. Forster, in the third polar expedition of Capt. Parry, held a conversation with a man across the harbor of Port Bowen, a distance of one and a quarter miles. Dr. Young states on the authority of Derham, that the watch-word "all's well" has been distinctly heard from Old to New Gibraltar, a distance of ten miles. The marching of a company of soldiers may be heard, on a still night, at from five hundred and eighty, to eight hundred and thirty paces; a squadron of cavalry at foot pace, at seven hundred and fifty paces; trotting, or galloping, one thousand and eighty paces distant. When the air is calm and dry, the report of a musket is audible at one thousand paces. The sound of the cannonading at Waterloo, was heard at Dover.

Sounds travel further and more loudly on the earth's surface than through the atmosphere. Thus it is said, that at the siege of Antwerp in 1832, the cannonading was heard in the mines of Saxony, which are about three hundred and twenty miles distant; the cannonading at the battle of Jena was heard feebly in the open fields at Jena, but in the casemates of the fortifications it was heard with great distinctness. The noise of a sea fight between the English and the Dutch in 1672, was heard at Shrewsbury, a distance of two hundred miles. The greatest known distance to which sound has been carried by the atmosphere, is three hundred and forty-five miles; as it is asserted, that the very violent explosions of the volcano at St. Vincent's have been heard at Demarara.

433. **Reflection of sound.**—When the waves of air on which sound is being borne impinge, in the course of their expansion, on a solid surface, they will be reflected from it, agreeably to the laws regulating the impact of solid bodies. (127.) Their return is made with equal velocity, and under an equal but opposite angle to that under which they advanced.

434. **Echo.**—An echo is the repetition of a sound reflected by a sufficiently distant object, so that the reflected is not confounded with the direct sound.

Upon what does it depend? How does the intensity of sound diminish? How far is a human voice audible? What is said of a conversation held across the harbor of Port Bowen? How far may the marching of different troops be heard? Mention some great distances at which battles and sieges have been heard. What is the greatest distance sound is known to have been carried? 433. What is said of the reflection of sound? 434. What is an echo?

A good ear cannot distinguish one sound from another, unless there is an interval of one-ninth of a second between the arrival of the two sounds. Sounds must, therefore, succeed each other at an interval of one-ninth of a second, in order to be heard distinctly. Now the velocity of sound being eleven hundred and twenty feet a second, in one-ninth of a second the sound would travel one hundred and twenty-four feet. To have a perfect echo, therefore, the reflecting surface must be at least sixty-two feet from the sounding body. ($62 \times 2 = 124$.) If we speak a sentence at the distance of sixty-two feet from the reflecting surface, we shall hear the echo of the last syllable only. If twice, thrice, or four times the distance, two, three, or four of the syllables will be echoed, the direct sounds, and reflected sound of the other syllables of the sentence being confounded with each other. If the reflecting surface is at a less distance from the sounding body than sixty-two feet, the direct sound, and the reflected sound become confused, so that words and tones cannot be heard distinctly. The original sound will then be prolonged and strengthened, an effect which we express in saying there is resonance. If the distance is comparatively small, as in a common sized room, the sounds reflected from the walls, the ceiling and the floor, reach the ear at almost exactly the same time as the direct sound, and the apparent power of the voice is strengthened, besides preserving its delicacy. Where, however, the apartment is larger, the direct sound only partially coincides with the reflected sound, and more or less confusion arises. Voices are heard in a remarkably sonorous manner, in large apartments with hard walls, while draperies, hangings, carpets, &c.., about a room, smother the sound, because these are bad reflectors. A crowded audience has a similar effect, and increases the difficulty of speaking, by presenting surfaces unfavorable to reflection.

435. **Repeated echoes.**—Repeated echoes, or multiplied echoes, are those which repeat the same sound many times. This happens when two obstacles are placed opposite to one another, as parallel walls, for example, which reflect the sound successively.

What interval must there be between sounds in order to distinguish them? What must be the distance of the reflecting surface from the sounding body in order to form a perfect echo? What is the effect if the distance is two, three, or four times sixty-two feet? What if it is less? What is the effect if the distance is small, as in a room? What effect have hangings, carpets, &c., in rooms, upon voices?

At Ademach, in Bohemia, there is an echo which repeats seven syllables three times; at Woodstock, in England, there is one which repeats a sound seventeen times during the day, and twenty times during the night. An echo in the Villa Smionetta, near Milan, is said to repeat a sharp sound thirty times audibly. The most celebrated echo among the ancients, was that of the Metelli at Rome, which, according to tradition, was capable of repeating the first line of the Æneid, containing fifteen syllables, eight times distinctly. Dr. Birch describes an echo in Roseneath, Argylshire, which it is said does not now exist. When eight or ten notes were played upon a trumpet, they were returned by this echo upon a key a third lower than the original notes, and shortly after upon a key still lower. Dr. Page describes an echo in Fairfax County, Virginia, which possesses a similar curious property. This echo gives three distinct reflections, the second echo much the most distinct. Twenty notes played upon a flute, are returned with perfect clearness. But the most singular property of this echo is, that some notes in the scale are not returned in their places, but are supplied with notes which are either thirds, fifths, or octaves.

There is a surprising echo between two barns at Belvidere, Alleghany County, N. Y. The echo repeats eleven times, a word of either one, two, or three syllables; it has been heard to repeat thirteen times. By placing oneself in the centre, between the two barns, there will be a double echo, one in the direction of each barn, and a monosyllable will be repeated twenty-two times.

A striking and beautiful effect of echo is produced in certain localities by the Swiss Mountaineers, who contrive to sing their *Ranz des Vaches* in such time, that the reflected notes form an agreeable accompaniment to the air itself.

436. **Whispering galleries.**—Whispering galleries are so called, because a low whisper, uttered in one point in them, may be heard distinctly at another and distant point, while it is inaudible in other positions. Such galleries are always domed, or of ellipsoidal shape; the best form is that of the ellipsoid of revolution. In such a chamber, a person whispering in one focus, is very audible to a person at the other focus, because the undulations, striking upon the walls, are reflected to the point where the hearer is placed, while in any other position, a feeble sound, or

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435. What are repeated echoes? When does this happen? Mention some remarkable multiplied echoes. Mention the echo described by Dr. Page in Virginia. The one in Belvidere, N. Y. 436. What are whispering galleries? What is their form?

none at all, will be heard, because only a part of the reflected sound will reach the ear at one time. (See fig. 265.)

One of the halls of the museum of antiquities, of the Louvre, at Paris, furnishes an example of such an apartment. In the dome of the Rotunda of the Capitol at Washington, is a fine whispering gallery. The principal room of the Merchants Exchange, in New York, is of a similar character, and at the same time affords a painful example of confused echoes. The new Halls of Congress, at Washington, have been designed with special reference to the best form for public speaking, and to this end an elaborate series of experiments and observations, upon the best proportions and forms of public halls, have been undertaken by Profs. Henry and Bache, by order of the Government, the results of which are recorded by the former, in the Proceedings of the American Association for 1856, p. 119.

437. **Speaking tubes.**—In order to save the necessity of running from room to room with messages, speaking tubes are used in large establishments, as hotels, and manufactories. Words uttered at one end of the tube, are audible at the other, although it be at a considerable distance. For the divergent rays of sound entering one end of the tube, instead of being scattered through the surrounding atmosphere, are confined within the tube, whose inner surface causes waves of sound to be reflected. So that, at length they issue simultaneously from the opening of the tube within, as indicated in fig. 271.

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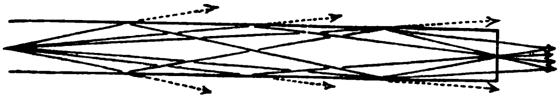

438. **Speaking trumpet.**—The speaking trumpet, fig. 272, is designed to transmit the voice to great distances. It is a tube, commonly funnel-shaped, but better of a parabolic form. A longitudinal section of the latter instrument is represented in fig.

272

Mention instances of whispering galleries? 437. What is the use of speaking tubes? How is the effect produced? 438. What purpose is a speaking trumpet designed to produce?

273. The rays of sound, which diverge from the mouth of the speaker at the focus *F*, are reflected parallel to the axis of the instrument. The trumpet being directed upon a person at a distance, a collection of parallel rays of sound reach his ear, in much greater number than the diverging rays would from the mouth of the speaker alone; so that sounds of audible intensity are conveyed to the hearer, which he could not perceive from the unassisted organs of speech. It has been proved by experiment, that the efficiency of this instrument increases with its length. A strong man's voice, sent through a trumpet from eighteen to twenty-four feet in length, may be heard at a distance of three miles. Similar in form to the speaking trumpet, is the bugle horn and common trumpet

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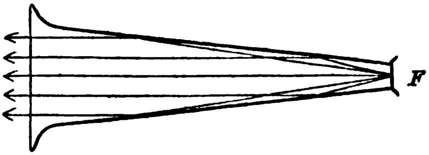

439. **Hearing trumpet.**—The hearing trumpet, fig. 274, intended to assist persons hard of hearing, is in form and application the reverse of the speaking trumpet, though in principle the same. The nearly parallel rays of sound enter the hearing trumpet at the large opening, while the small extremity is introduced into the ear. The form of the interior surface is such, that after one or more reflections, all the rays of sound that enter the instrument are united at the smaller end, so that the intensity of the sound which reaches the ear is increased many fold in consequence of it. Holding the hand concave behind the ear, as deaf persons are seen to do, concentrates sound in the manner of an ear trumpet. The form of the external ear favors the collection of sound in all animals.

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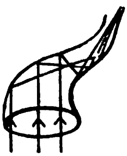

440. **The siren.**—This ingenious instrument was invented by M. Caigniard de la Tour, for the purpose of ascertaining the number of vibrations of a sonorous body, corresponding to any proposed musical sound.

What is its shape? How is the effect produced? How is its efficiency increased? At what distance may sound be propagated by means of it? 439. What is the hearing trumpet? Of what form is it constructed? 440. For what is the siren designed?

Fig. 275 shows the siren mounted on a wind chest, *E*, designed to supply a current of air. Fig's. 276, 277, show the interior details of the apparatus. The siren is constructed entirely of brass. It consists of a tube, *O*, about four inches in diameter, terminating in a smooth circular plate, *B*, fig. 277, which contains, at regular intervals near its circumference, small holes, which are pierced through the plate in an oblique direction. Another plate, *A*, turning very easily upon its axis, is placed as near as possible to *B*, without being in contact with it. This plate is pierced with the same number of oblique orifices as those in the plate *B*, but inclined in an opposite direction, as shown in fig. 276, *n*, *A* ; *m*, *B*.

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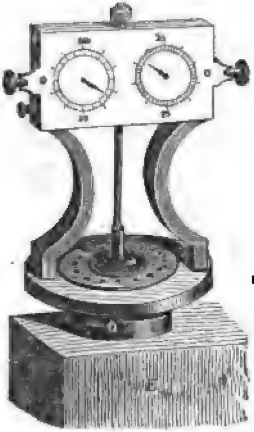

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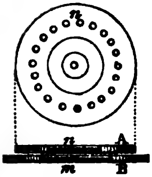

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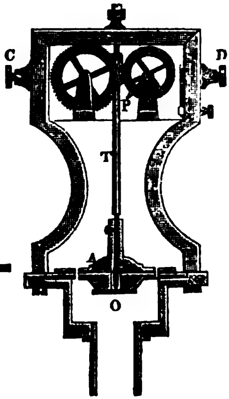

When a current of air arrives from the bellows, it passes through the holes of the first plate, and imparts a rotary movement to the second plate, in the direction *n*, *A*, fig. 276. As the upper plate revolves, the current of air is alternately cut off, and renewed rapidly by the constantly changing position of the holes. In consequence of this interruption, when the plate *B*, moves with a uniform velocity, a series of puffs of wind will escape at equal intervals of time. These puffs will produce undulations in the air surrounding the instrument, and when the wheel revolves with sufficient rapidity, a musical sound is produced, which increases in intensity as the velocity of the wheel becomes greater.

By whom was it invented? Describe the construction of the siren. What is the effect when a current of air arrives from the bellows? What is the object of the counter?

A counter, (like that on a gas meter,) is connected with the upper plate, by which the number of revolutions is indicated. Pressure upon the buttons, *C D*, fig. 277, causes the toothed wheels *a*, *b*, to be set in communication with the endless screw upon the spindle, *T*. The revolution of these wheels govern the motion of the hands upon the dials, in fig. 275. To determine the number of vibrations corresponding to a given sound, a blast of wind is forced from the bellows, into the siren, until it gives a corresponding note. The hands on the dials being brought to their respective zeros at the commencement of the experiment, their position, at the end of any known interval, will indicate the number of puffs of air which have escaped from the revolving plate, and will, consequently, determine the number of undulations of the air which correspond to the sound produced.

The siren, with equal velocity, gives the same sound, excepting the timbre, in the different gases, and in water, as it does in air, which proves, that the height of any sound depends on the number of vibrations, and not on the nature of the sonorous body.

441. **Savart's toothed wheel.**—Savart has employed another apparatus to count the number of vibrations corresponding to any proposed pitch.

It consists, fig. 278, of a toothed wheel, *D*, to be revolved as regularly as possible, by means of the wheel, *R*, and endless band *r*.

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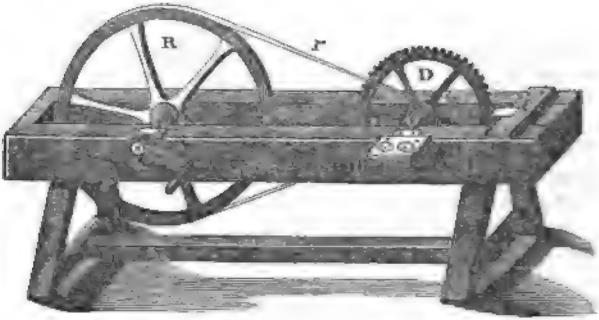

The toothed wheel, *D*, revolving rapidly, makes the tongue, *C*, vibrate, producing in the air corresponding undulations, the effect of which is a musical sound. As the tongue is struck on the passage of each tooth, the number of vibrations in a second will correspond

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How do we determine the number of vibrations corresponding to a given sound? 441. Describe the construction of Savart's toothed wheel.

with the number of teeth which have struck the tongue in the same time. This is learned from the dial plate, *O*, which indicates the number of revolutions of the axis, and multiplying this by the number of teeth, we have the whole number of vibrations in a given time. Upon revolving the wheel slowly, we may hear the successive shocks of the teeth against the tongue, and as we increase the velocity, we obtain a more and more elevated sound.

442. **Music halls.**—Music halls, theatres, &c., should be so constructed as to convey the sounds that are uttered, throughout the space occupied by the audience, unimpaired by any echo or conflicting sound. On theoretical grounds, the best form for the walls would be that of a parabola. Ornaments, pillars, alcoves, vaulted ceilings, all needless hollow and projecting spaces, break up and destroy the echoes, and resonances. The height of a room for public speaking should be not more than from thirty to thirty-five feet; for at this point, called the limit of perceptibility, the reflexion and the voice will blend together well, and thus strengthen the voice of the speaker; if it is higher than this, the direct sound and the echo will begin to be heard separately, and produce indistinctness. (434—436.)

2.—*Physical Theory of Music.*

443. **Qualities of musical sounds.**—Musical sound is the result of continuous vibrations, rapid and isochronous, producing on the organs of hearing a prolonged sensation. The ear distinguishes three particular qualities in sound. 1.—The *tone* or *pitch*, in virtue of which sounds are high or low. 2.—The *intensity*, in virtue of which they are loud or soft; and 3d,—a property expressed by the word *timbre*, (for which we have no exact English equivalent.)

444. **1.—Tone or pitch.**—The tone or pitch of a musical sound is grave or acute. It depends on the rapidity of the vibratory movement. The more rapid the vibrations are, the more acute will be the sound. Grave sounds are often loud, because, in order to produce them, there must be quick vibrations, which are generated by forcible impulses.

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442. How should music halls, &c., be constructed? What is the best form theoretically? What is the effect of ornaments, pillars, &c.? What is the limit of height of a room for public speaking? 443. What are musical sounds? 444. What is meant by tone or pitch?

445. **2.—Intensity or loudness.**—The intensity, or force of sound, depends on the amplitude of the oscillations; that is, upon the degree of condensation produced at the middle of the sonorous wave.

The same sound may have the same degree of gravity or acuteness, and take a greater or less intensity, according as the amplitude of the oscillations varies. Thus, if we vibrate a tense cord, the intensity of the tone will vary, as the distance which the vibrating parts pass on each side of the line of rest.

446. **3.—Timbre.**—Timbre is that quality in sound which allows us to distinguish, perfectly, between sounds of the same pitch, and the same intensity.

Thus, the sounds produced by the flute and clarionet, are at once distinguished. The timbre of instruments, appears to depend not only on the nature of the sonorous body, and the surrounding bodies set in vibration by it, but also on the form and material of the instrument; and probably, also, on the form of the curve of vibration.

447. **Unison.**—Sounds produced by the same number of vibrations per second, are said to be in unison; they are then equally grave or acute.

Thus the siren (440,) and Savart's (441,) wheel, are in unison when we cause them to make the same number of vibrations in the same time.

448. **Melody.—Harmony.**—Melody in music consists of a succession of notes, having a simple numerical relation to each other, and producing an agreeable impression on the ear. The combination of such sounds, at proper intervals, produces a chord, and a succession of chords, constitutes harmony. By measure, is understood, making the duration of the notes or strains correspond with certain regular divisions of time, analogous to the metre and rhythm of poetry.

449. **Musical scale.—Gamut.**—The musical scale is formed of seven different sounds, (without counting the octave,) which are in the most simple relation to each other, and which in combination form tunes. This series of sounds is called the gamut, or diatonic scale. The sounds which compose it are the notes of

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445. Upon what does the intensity of a sound depend? 446. What is the timbre of a sound? Upon what does it depend? 447. When are sounds in unison? Give an illustration. 448. What is melody in music? What is meant by measure? 449. What is the musical scale? What is this series of sounds called?

music. They are designated, in English, by the letters C, D, E, F, G, A, B. In French and Italian, by the words ut, or do, re, mi, fa, sol, la, si.

We may also represent the notes of the gamut in numbers. In order to find the relation which exists between the fundamental note, C, or do, and the other notes, the sonometer, or monochord, fig. 279, is employed.

450. **The sonometer or monochord.**—This instrument is used to study the transverse vibrations of cords; and by it we ascertain the relation between the different notes of the musical scale, and, with the aid of the siren, (440,) the number of vibrations by which they are respectively produced.

Over a case of thin wood, a cord, or metallic wire, *A*, *D*, is stretched over the pulley *n*, by the weights *P*, on the pan *m*, fig. 279. The movable bridge, *B*, can be placed at any desired point; and for convenience of adjustment, the scale is marked off beneath the wire, commencing with *C*. The string, *A D*, when vibrating its whole length, produces the note *C*; in order to produce the note *D*, the movable bridge, *B*, must be advanced toward the fixed bridge *D*, until the length of the cord is but eight-ninths of that which produces the note *C*. Proceeding in the same manner for the other notes, it will be found, that the length of cord corresponding to each note, is represented by the following fractions.

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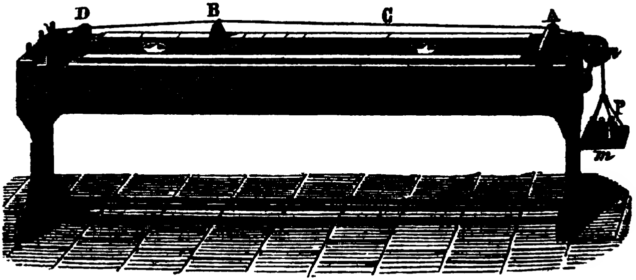

Notes - -	C.	D.	E.	F.	G.	A.	B.
Relative length of cord,	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$

In continuing to move the bridge on the sonometer, it will be

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How are these sounds designated in English? How in French? 450. What is the object of the sonometer? What has been ascertained from it? Describe its construction. How is the numerical relation between the different sounds determined? What is the relaitve length of the different cords? What relation does the eighth sound bear to the fundamental sound? What is said of other octaves?

found, that the eighth sound, the octave, is produced by a length of cord half that of the fundamental sound. Upon this note, an octave higher than the fundamental note, we may construct a scale, each note of which is produced by the vibration of a cord half as long as the same note in the preceding gamut. In the same manner we may have also a third and a fourth scale.

451. **Relative number of vibrations corresponding to each note.**—In order to ascertain the relative number of vibrations corresponding to each note in the same time, it is sufficient to reverse the fractions of the preceding table. For by the principles already established, (389,) the number of vibrations is in inverse ratio of the length of the string. Representing, therefore, the number of vibrations corresponding to the fundamental note C, by 1, proceeding as above, we form the following table :

Notes, - -	C.	D.	E.	F.	G.	A.	B.
Relative number of vibrations,	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$

Which indicates, that in producing the note D, nine vibrations are made in the same time that eight are made by the fundamental note C. So, when the note E is sounded, five vibrations are made for four of C; for B, fifteen to eight of C, &c.

452. **Absolute number of vibrations corresponding to each note.**—By setting the siren, or Savart's wheel, in unison with a given sound, we obtain the absolute number of vibrations corresponding to it. If we set the siren in unison with the fundamental C, in order to obtain the number of vibrations corresponding to the other notes, as D, we have but to multiply it by the fraction $\frac{9}{8}$, &c. But the fundamental C varies with the nature, length, and tension of the cord of the sonometer, and therefore the number of vibrations may be represented by an infinite variety of numbers, corresponding to the different scales. The notes of the scale whose gamut corresponds to the gravest sound of the bass, are indicated by 1. To notes of gamuts more elevated, are affixed the indices 2, 3, &c.; to graver notes are affixed the indices, —1,—2, &c. The number of simple vibrations corresponding to the note C, is 128, and in order to obtain the number of vibrations corresponding to the other notes, we have

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451. How are the relative numbers of vibrations corresponding to each other determined? What are these numbers? What do these numbers indicate? 452. How is the absolute number of vibrations corresponding to each note found? How are the different gamuts indicated?

but to multiply this number by the fractions indicated in (451,) which gives the following table.

Notes, - - -	C.	D.	E.	F.	G.	A	B.
Absolute number of simple vibrations,	128	144	160	170	192	211	240

The absolute number of vibrations for the superior gamut, is obtained by multiplying the numbers in the table successively, by 2, by 3, by 4, &c.; for the lower gamut, we divide the same numbers by 2, by 4, &c. Thus, the number of vibrations of A3 is 214 × 4 = 856 simple vibrations, or 428 complete vibrations.

It must, however, be stated, that there is a slight difference of opinion as to the actual number of vibrations producing a particular note. Thus A3 of the pitch adopted at different orchestras, which in the above table is stated to be produced by 428 vibrations, varies as follows:

Orchestra of Berlin Opera, - - - -	437·32
Opera Comique, Paris, - - - -	427·61
Academie de la Musique, Paris, - - -	431·34
Italian Opera, " - - -	424·14

In piano-fortes, which, for private purposes, are generally tuned below concert pitch, A3, is produced by about 420 vibrations in a second.

There has been a curious progressive elevation of the diapason (pitch) of orchestras, since the time of Louis XIV, when the *la* in the orchestra was (according to Sauveur) 810 simple vibrations, (= 405 complete vibrations,) per second; the number at the grand opera is now 898, or nearly a tone higher. This rise has taken place mainly in the present century—being a semi-tone since 1823. The comparative rarity of tenor voices has been thus accounted for. The causes of this change, (which is still in progress,) would demand some space to explain. But the prevalence of military music with wind and stringed instruments, is a principal cause.

453. **Length of sonorous waves.**—It is easy to ascertain the length of a sonorous vibration, if we know the number of vibrations made in a second. For, as sound travels at the rate of 1118 feet per second, if but one vibration is made in that time, the length of the wave must be 1118 feet; if two vibrations, the length of each must be half of 1118, = 569 feet, &c.

What is the number of vibrations corresponding to the different notes? How are the number of vibrations for the notes of other gamuts obtained? What is stated as the actual number of vibrations producing a particular note? 453. How is the length of sonorous vibrations ascertained?

C, corresponds, as we have seen, to 128 vibrations per second; the length of its waves is, therefore, (1118 + 128,) = 8·73 feet.

The following table indicates the length of the waves corresponding to the C of successive scales.

	Length of waves in feet.	Number of vibrations in a second.
C—3	70·	16
C—2	35·	32
C—1	17·5	64
C—1	8·73	128
C—2	4·375	256
C—3	2·187	512
C—4	1·093	1024

454. **Interval.**—Interval is the numerical relation existing between the number of vibrations made in the same time by two sounds, or it is that which indicates how much one sound is higher than another.

The interval of C to D, is called a second; of C to E, a third; of C to F, a fourth; of C to G, a fifth; of C to A, a sixth; of C to B, a seventh; of C to C, an octave. The following table gives the intervals of successive notes, obtained by dividing the vibrations of one note, by the vibrations of the note immediately preceding it.

Notes, - - -	C.	D.	E.	F.	G.	A.	B.	C.
Relative number of vibrations,	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Interval, - -		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

It may be observed, that there are but three different intervals, $\frac{9}{8}$ $\frac{10}{9}$ $\frac{16}{15}$. The first is called major tone. The second minor-tone. The third major-semi-tone. A comma is the interval between the minor tone $\frac{10}{9}$, and the major tone $\frac{9}{8}$ is $\frac{80}{81}$, differing from a unit but by $\frac{1}{81}$. Unless the ear is well trained, it cannot appreciate this difference, just as the eye is not disturbed by small alterations in the proportion of objects, the symmetry and form of which are pleasant.

455. **Flats and sharps.**—If we wish to write a tune with scales more or less grave, it would seem necessary to take the notes in different octaves. But from one octave to another, there is too great a difference in most cases, and the scope of our instruments would not permit us to find all the sounds needed.

Musicians have therefore inserted, betwen the sounds of the natural gamut, intermediate sounds, which are designated under the

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Give the length of the waves corresponding to the C of successive scales. Give the number of vibrations per second. 454. What is an interval in music? What are the different intervals? How many intervals are there? What is said of the comma? 455. What are flats and sharps?

name of flats and sharps. These intermediate sounds bear the name of the lower note, followed by the word *sharp*, or of the upper note followed by the word *flat*. A note sharped or flatted, is elevated or lowered in the musical scale in such a manner, that the rapidity of its vibrations is increased or diminished in a certain ratio which varies for the different parts of the scale. Therefore, between all notes of the natural gamut, there are two intermediate sounds, a flat and a sharp. In music, the sharp is indicated by the sign (♯) and the flat by the letter (*b*.)

456. Concord and discord.—Concord is the simultaneous production of many sounds, producing on the ear an agreeable sensation. Concord only takes place when the difference in the number of vibrations of simultaneous sounds is in a simple ratio, so that the ear readily discovers the relation. If the ratio is complicated, the ear is disagreeably affected, and discord results.

The most simple concord is, evidently, unison (447,) in which the two sounds correspond to the same number of vibrations. After unison, comes the octave; of which one of the two sounds has double the number of vibrations of the other. Representing the fundamental sound by 1, the acute octave will be represented by 2, and the grave octave by $\frac{1}{2}$. Consequently, every alternate vibration of the upper note, coincides with the commencement of the lower. After the octave, the most simple concords, are the fifth, $\frac{3}{2}$, the sharp note being produced by three vibrations, while the grave note is produced by two in the same time, correspoding to the interval C to G. This concord is termed a fifth, because the note G is the fifth from C. A similar explanation applies to the numerical names of the other concords.

The fourth, or $\frac{4}{3}$, corresponds to the interval C to F.

The major third, or $\frac{5}{4}$, corresponds to the interval C to E.

The minor third, or $\frac{6}{5}$, is the interval E to G.

In fig. 280, the dots represent musical notes; those vibrations which occur simultaneously, and therefore increase each other's power, are connected by vertical lines.

How is a note sharped? How is a note flatted? 456. What is concord? When does concord take place? When does discord result? What is the most simple concord? Which is most simple after unison? What is the fifth? Mention the other concords. Show their relation to each other.

Thus the most simple concords are those in which the vibrations of the sounds are between themselves, as the numbers 4 : 3, 5 : 4, 6 : 5.

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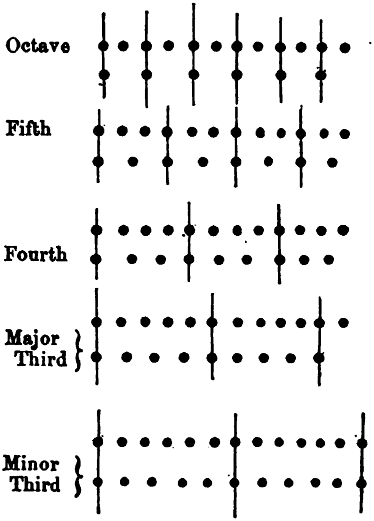

457. **Perfect concord.** Perfect concord, which produces on the ear the most agreeable musical sensation, is formed with three sounds, of which the number of vibrations is in the most simple relation between themselves and the fundamental sound. In the most agreeable accord, the relation between these sounds is 4, 5, 6. Thus, C E G. G B D, form two perfect accords.

458. **Chromatic scale.** In the diatonic scale, as we have seen, the intervals, though nearly equal, do not correspond. In order to do away with this inequality semi-tones have been introduced between the entire tones. The octave is thus made to consist of seven natural and five semitones. But even in this, *the chromatic scale*, the intervals are not perfectly equalized, though in practical music it is assumed that they are so.

459. **Beating.**—When two sounds are produced at the same time which are not in unison, alternations of strength and feebleness are heard, which succeed each other at regular intervals.

This phenomenon, called beating, discovered by Savart, is easily explained. Supposing that the number of vibrations of the two sounds was 30 and 31; after 30 vibrations of the first, and 31 of the second, there would be coincidence, and in consequence, beating, while at any other moment, the sonorous waves not being superinposed, the effect would be less. If the beatings are near to each other,

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457. What is perfect concord? Mention the perfect concords. 458. What is said of the chromatic scale? 459. What is beating? How is it explained?

there is produced a continuous sound, which is graver than the two sounds which compose it, since it comes from a single vibration, while the other sounds are made of 30 and 31 vibrations.

460. **Diapason, tuning-fork.**—The diapason is a familiar instrument, with which we may produce, at will, an invariable note; its use regulates the tone of musical instruments. It is formed from a bar of steel, curved, as seen in fig. 281. It is sounded by drawing through it a smooth rod of steel, large enough to spring open the limbs, and its vibrations are greatly strengthened to the ear by mounting it, as in the figure, upon a box of thin wood, open at one end. A diapason, giving C3, or 256 vibrations in a second, produces a sound comparable with that from an organ tube.

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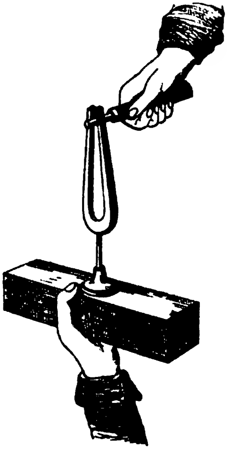

The diapason is ordinarily formed to produce A3, corresponding to 428 vibrations in a second.

The whole diatonic scale is thus conveniently constructed, by a series of diapasons, arranged as in fig. 282, upon a sounding-box, *A A*.

461. **Sensibility of the ear.**—According to Savart, the most grave note the ear is capable of appreciating, is produced by from seven to eight complete vibrations per second. When a less number is made, the vibrations are heard as distinct and successive sounds.

The most acute musical sound recognized, was produced by 24,000 complete vibrations per second. Savart maintains, however, that this is not the extreme limit of the sensibility of the ear, which is capable of wonderful training. The same physicist has also demonstrated, that two complete vibrations are sufficient to

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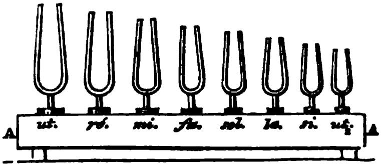

What is the result if the beatings are near to each other? 460. What is the tuning-fork? How may the sound be strengthened? 461. Which is the most grave note the ear can appreciate? Which is the most acute musical sound recognized?

enable the ear to determine the rapidity of these vibrations; that is, the height of the sound produced. If his wheel made 24,000 vibrations in a second, the two require but $\frac{1}{12,000}$th of a second. The ear may, therefore, compare sounds which act only during this wonderfully brief interval.

Many insects produce sounds so acute as to baffle the human ear to distinguish them; and naturalists assert, that there are many sounds in nature too acute for human ears, which are yet perfectly appreciated by the animals to which they are notes of warning, or calls of attraction.

8.—*Vibration of air contained in tubes.*

462. **Sonorous tubes.—Mode of vibrating.**—In wind instruments, with walls of suitable thickness, the column of air contained in the tubes alone, enters into vibration.

The material of the tube has no influence upon the sound, but effects the *timbre*, (446,) in a striking and important manner. The pitch of the sound produced, depends partly on the size and situation of the embouchure; still more on the manner of imparting the first movement to the air, and partly also on varying the length of the tube containing the column of air.

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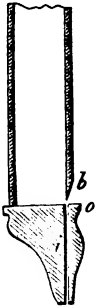

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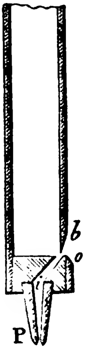

Sonorous vibrations are produced in tubes in a number of ways. 1.—By blowing obliquely into the open end of a tube, as in the Pandean pipe. 2.—By directing a current of air into an embouchure, or near the closed end of the tube. These tubes are called mouth pipes. 3.—By thin vibrating laminae of metal, or of wood, called reeds, or by the vibration of the lips, acting as reeds. 4.—By a small flame of hydrogen gas.

463. **Mouth-pipes.**—Fig. 283 represents the embouchure of an organ tube, fig. 284, that of a whistle or flageolet. In these two

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How many vibrations are necessary before the height of the musical sound may be determined? What of sounds too acute for human ears? 462. What is said of the vibration of wind instruments? Upon what does the pitch of the sound depend? How are sonorous vibrations produced in tubes?

figures, the air is introduced by the opening, *i*, (called the *lumière*); *b o*, is the mouth, of which the upper lip is beveled. The foot, *P*, fig. 284, connects the pipe with a wind-chest. When a rapid current of air passes through the inlet, it encounters the edge of the upper lip, which partially obstructs it, causing a shock, so that the air passes through *b o* in an intermittent manner. These pulsations are transmitted to the air in the tube, making it vibrate, and producing a sound.

In order to have a pure sound, there must exist a certain relation between the dimensions of the lips, the opening of the mouth, and the size of the lumière. Again, the length of the tube must bear a certain ratio to its diameter. In those wind instruments, like the flute, flageolet, &c., in which various notes are produced by the opening and closing of holes in their sides by means of fingers or keys, there is a virtual variation in the length of the tube, which determines the pitch of the various notes produced. The number of vibrations depends upon the dimensions of the tube and the velocity of the current of air.

464. **Reed pipes.**—A reed is an elastic plate of metal, or of wood, attached to an opening in such a manner, that a current of air, passing into the opening, causes the plate to vibrate. This vibration is propagated to the surrounding air. Reeds are found in hautboys, bassoons, clarionets, trumpets, and in the Jewish harp, which is the most simple instrument of this species.

Fig. 285 represents a reed-pipe, mounted on the box of a bellows, *Q*. A glass, *E*, in one of the walls of the tube, allows the vibrations of the reed to be seen. The case, *H*, serves to strengthen the sound. Fig. 286 represents the reed separated from the tube. It is composed of a rectangular case of wood, closed at its lower end, and open at the top, at a point *o*. A plate of copper, *c c*, contains a longitudinal opening, designed to allow the passage of the air from the tube, *M N*, through the orifice *o*. An elastic plate, *i*, almost closing the aperture, is confined at its upper end. The sliding rod, *r*, curved at its lower end, permits the regulation of the pitch, by alterations in the length of the vibrating part of the plate.

When a current of air passes in through the foot, *P*, the reed vibrates, alternately opening and closing the aperture. The vibrations being very

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463. How is the air thrown into vibration in mouth pipes? Upon what does a pure sound depend? What is the use of the keys? 464. What is a reed? What is the construction of the reed? What is the action of a current of air passing into the pipe?

rapid, the sound produced varies in pitch with the velocity of the current. This sound is transmitted to the exterior air through the opening *o*.

In this kind of reed, the vibrating plate passes through the aperture, without its walls, and the tone is remarkably pure and free from any harshness.

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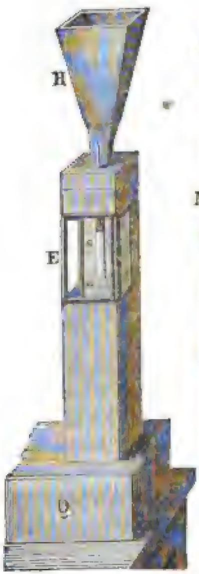

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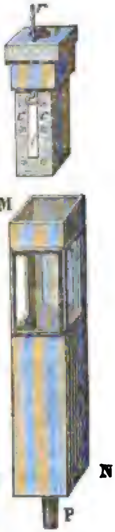

In the French horn, the trumpet, and other similar instruments, the sound is produced by the vibration of the lips of the performer, acting like reeds.

465. **Gas jet.**—A jet of hydrogen gas, or of common illuminating gas, burned within a tall tube of glass, or other material, occasions, if accurately adjusted, a musical note. A simple form of this arrangement is seen in fig. 287, where hydrogen, generated by the action of dilute sulphuric acid on zinc in the bottle, is burned from the narrow glass tube, within one of larger dimensions. It is better to take the gas from a reservoir, or gas jet, with a key interposed, to regulate the volume of the flame. The cause of the vibrations and sound in this case is to be found in the periodical explosions of small portions of free gas, mingled with common air. The heat occasions a powerful ascending current of air, momentarily extinguishing the flame, and at the same instant permitting the mixture of the atmospheric oxygen with a portion of inflammable gas. The expiring flame kindles this explosive mixture, and relights the jet. As these successive phenomena occur with great rapidity, and at regular intervals, the necessary consequence is a musical note.

466. **Musical instruments.**—The principles already explained in this chapter, will illustrate the peculiar power of the several

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In what instruments do the lips act as reeds? 465. Explain the vibrations from a gas jet. What causes the sound? 466. What is said of wind instruments? How are these instruments sounded?

sorts of musical instruments in common use. It is inconsistent with our limited space to describe, in detail, these several instruments. Such details belong to a special treatise on music. Musical instruments are divided, chiefly, under the head of wind and stringed instruments, and those like the drum, in which a membrane is the source of vibration.

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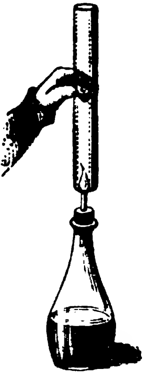

Wind instruments are sounded, either with an embouchure, like a flute, or with reeds. The first division includes the flute, pipe, flageolet, &c., and in the second are found the clarionet, bassoon, horns, trombones, &c. The organ also belongs to this division, and is, incomparably, the grandest of all musical instruments, as its power and majesty is without parallel in instrumental combinations.

Stringed instruments are all compound instruments. The sounds produced by the vibration of the cords, are strengthened by elastic plates of wood, and inclosed portions of air, to which the cords communicate their own vibrations. They are vibrated either by a bow, as in the violin, by twanging, as in the harp, or by percussion, as in the piano.

Drums are of three sorts; the common regimental or snare drum, which is a cylinder of brass, covered with membrane, and beaten on one end only; the bass, or double drum, of much larger dimensions, and beaten on both heads; and thirdly, the kettle drum, a hemispherical vessel of copper, covered with vellum, and supported on a tripod. This drum has an opening in the metallic case, to equalize the vibrations. They all depend, of course, upon the vibration of tense membranes. (398.)

467. **Laws of Bernoulli on the vibration of air in tubes.**—The following laws of the vibration of air contained in tubes, were discovered by Daniel Bernoulli, a celebrated geometrician who died in 1782. We may divide the tubes into two classes.

a.—Tubes of which the extremity opposite the mouth is closed.

b.—Tubes open at both extremities.

a.—Tubes of which the extremity opposite the mouth is closed.

1st.—The same tube may produce different sounds, the number of vibrations in which will be to each other as the odd numbers 1, 3, 5, 7, &c.

Name some in each class of stringed instruments. How are they sounded? What of drums? What peculiarity is in the kettle-drum?

2d.—In tubes of unequal length, sounds of the same order correspond to the number of vibrations, which are in inverse ratio of the length of the tubes.

3d.—The column of air vibrating in a tube, is divided into equal parts, which vibrate separately and in unison. The open orifice being always in the middle of a vibrating part, the length of a vibrating part is equal to the length of a wave corresponding to the sound produced.

b.—Tubes open at both extremities.

The laws for tubes open at both extremities, are the same as the preceding, excepting that the sounds produced are represented by the series of natural numbers, 1, 2, 3, 4, &c.; and that the extremities of the tubes are in the middle of a vibrating part. Again, the fundamental sound of a tube open at both extremities, is always the acute octave of the same sound in a tube closed at one extremity.

468. **Results of experiment.**—The laws of Bernoulli are not exactly confirmed by experiment. With tubes having a bouche, or reed, graver sounds are obtained than those indicated by theory. That these laws may accord with theory, tubes must be used, of which the section is very small in relation to the length, and the air must be set in vibration in all the circumference of the tube, and not on a single side, as is generally done.

VOCAL AND AUDITORY APPARATUS.

THE VOICE.

469. **Vocal apparatus of man.**—The vocal apparatus of man consists essentially of three parts, the trachea, the larynx, and the mouth. The lungs and trachea perform the part of a bellows or wind chest of an organ. The larynx corresponds to the mouth-piece, or that part of the organ tube which gives the peculiar character to the sound. The mouth and nasal passages correspond to that part of the tube above the mouth-piece from which the vibrations of the column of air are thrown into the atmosphere. The air comes from the lungs through the trachea,

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467. What are the laws of Bernoulli on the vibration of air in tubes of which one extremity is closed? What the laws when both extremities are open? 468. What results are obtained by experiment? 469. Of what does the vocal apparatus of man consist? What office does each of these parts perform?

which is a tube formed of cartilaginous rings, and is delivered into the larynx, an organ nearly closed by two membranes.

Müller has shown that the larynx is essentially a reed instrument, furnished with a double membranous tongue. In this the voice is produced; for if an opening is pierced in the trachea, below the larynx, the air escapes by this opening, and it is not possible to produce a sound. If an opening is made above the larynx, it does not prevent the formation of sound. Magendie mentions the case of a man who had a fistulous opening in his trachea, and who could not speak unless he closed it, or wore a tight cravat.

470. **The Larynx.**—This organ is composed essentially of four pieces of cartilage, called respectively the thyroid, cricoid, and the two arytenoid cartilages. In fig. 288, showing a vertical section through the larynx and glottis, the position of the thyroid and cricoid cartilages is seen in *bb*, *dd*. The thyroid cartilage is made of two flat plates whose upper edges are curved somewhat like the letter *S*, and forms a prominent projection on the throat of man, visible exteriorly, and vulgarly called Adam's Apple. The cricoid cartilage, *aa*, lies below the thyroid cartilage, and is in fact only an enlargement of one of the cartilaginous rings forming the wind-pipe. The position of the arytenoid cartilages is over the cricoid cartilages. These several cartilages, with the hyoid bone, serve as points of attachment for the muscles forming the proper vocal apparatus. The two chief tongues of the glottis, or proper vocal cords, *cc*, extend from the thyroid cartilage to the arytenoid cartilages, and leave between them a fissure, the *rima vocalis*, or glottis, shown better in fig. 289. This fissure leads on one side into the trachea, which lies below the larynx, and on the other into the cavity of the larynx itself, which communicates with the cavities of the mouth and nose.

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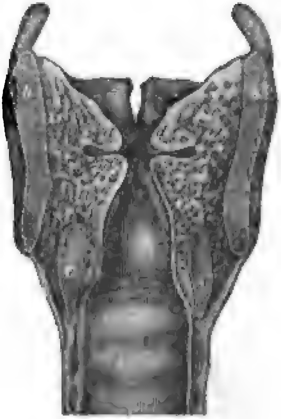

Besides the proper vocal cords, there are the ventricular cords, *d d*, situated a small distance above them in the epiglottis; they are less devel-

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What does Müller say of the larynx? 470. Describe the larynx. Where is the glottis situated? Describe fig. 288.

oped than the first. The ventricular cords have no part in the production of vocal sounds, which, however, they doubtless serve to modify and strengthen in the same way as the conical case surmounting an organ tube. (See H, fig. 285.)

Between these two sets of cords are seen the deep depressions, called the ventricles of the glottis.

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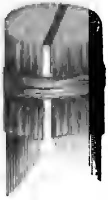

471. **The Glottis.**—A clear idea may be obtained of the form and action of the glottis, by supposing two pieces of India rubber stretched over the orifice of a tube, so that a small fissure is left between them, fig. 290.

By forcing air through such a tube, sounds will be produced, varying with the tension of the membranes and the dimensions of the aperture. The glottis is a fissure-like opening, bounded by similar membranes. By means of a series of small muscles, the vocal cords may be extended or relaxed, at pleasure, while other muscles afford the power of altering the width of the vocal fissure.

472. **Mechanism of the voice.**—The formation of sound in the larynx, as has been already suggested, is produced by the vibration of the vocal cords, acting as a species of membranous reed, under the influence of air from the lungs. The sound being produced as in ordinary reeds (464) by the intermittent current of air.

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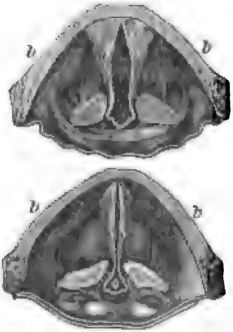

The glottis is the original seat of the sound, and although other parts of the respiratory apparatus have a certain influence in modifying the tone, they have no share whatever in the production of the sounds, or in determining their pitch.

When at rest, the lips of the glottis are wrinkled and plicated, so that the air in respiration passing through the fissure fails to put the membranes in vibration. But as the musician tunes his instrument by increasing or diminishing the tension of its vibrating strings, so something like this occurs with the human larynx. These

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What is said of the ventricular cords? 471. How may a clear idea of the glottis be obtained? How are the vocal cords moved? 472. How is sound produced in the larynx? What is the original seat of sound? How are sounds produced by the glottis? Describe fig. 289.

two conditions of the glottis are beautifully shown by the two parts of fig. 289, from Muller. The upper shows the organ at rest, the vocal cords, *cc*, being relaxed, while in the lower, these cords are shown as in the act of vibrating; the small air passage, *o*, opening into the trachea is never closed. When sounds are to be produced, the fissure is contracted and the membranes receive the degree of tension necessary for vibration. The sound varies according to the tension of the membranes, the magnitude of the fissure and the form and magnitude of the passages, through which the air, thus put in vibration, passes before it issues into the atmosphere.

473. **Range of the human voice.**—In speaking, the range of the human voice is subject to but very little variation, being generally limited to half an octave. The entire range of voice in an individual is rarely three octaves, but the male and female voice taken together may be considered as reaching to four.

Voices are variously denominated according to the extreme limits of their register proceeding from the highest to the lowest in the scale, as follows: soprano, contralto, tenor and basso. The soprano and contralto are voices found only, (with rare exceptions,) in females and children; the tenor and basso are men's voices. There are intermediate complications among them, the mezzo-soprano intervening between the contralto and soprano, and the barytone between the tenor and the basso.

Since every individual organ differs from another, no exact limits can be assigned to these several classes of organs. The mean limits, however, for each of these three classes, as determined from the experiments of Caignard de la Tour, Savart, and others, is as follows, the numbers annexed being the number of double vibrations of the glottis produced in a second of time.

Soprano,	1056 264	Mezzo-Soprano,	930 220	Contralto,	704 176
Tenor,	528 132	Barytone,	352 110	Basso,	220 82.5

474. **Ventriloquism, stuttering, &c.**—*Ventriloquism* is supposed by many investigators to consist chiefly in the use of in-

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473. What is the range of the voice in speaking? What is the entire range of the male and female voices? How are voices classified? Give the number of vibrations of the glottis for the soprano, tenor, contralto, basso, &c.

spiratory sounds; this is true only to a certain extent. The art of the ventriloquist depends greatly on the correctness of ear and flexibility of organ, through which common tones are modulated to the position and character in which the imaginary person is supposed to speak: other means often being used to heighten the deception, as concealing the face that the play of organs may not be observed; often in speaking with expiratory notes, the air expelled by one expiration is distributed over a large space of time, and a considerable number of notes.

In stuttering the several organs of speech do not play in their normal succession, and thus are continually interfered with in convulsive impulses and inefficient adjustments. The cause of this result lies almost wholly in the nervous apparatus which rules over the organs of speech. One important remedial means is to study carefully the articulation of the difficult letters, and to practice their pronunciation repeatedly and slowly.

In deaf and dumb persons the organs of speech have originally no essential defects. The true cause of their dumbness lies in their inability to perceive sound. The impossibility of appreciating the several sounds, and thus gradually acquiring the power of properly adjusting the organs of speech, is the chief reason why the second infirmity is associated with the first.

475. **Production of sounds by inferior animals.**—*Mammifers.* Voice is common to all mammifers, but speech, (the articulation of vocal sounds,) is the peculiar privilege of man. The sounds which the different animals produce are peculiar to the class to which they belong, thus the horse neighs, the dog barks, the cat mews, &c. These various modifications depend on the peculiar structure of the larynx, but more upon the form and dimensions of the nasal and other cavities, through which the vibrating air passes.

The cat is distinguished from other mammifers by the almost equal development of the inferior and superior vocal cords. Many of its notes are almost human. The horse and ass are supplied with only two vocal cords.

Animals which howl, and are heard at great distances, have generally large laryngeal ventricles.

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474. What is said of ventriloquism? What means are used to heighten the deception? What is said of stuttering? What is the cause of this result? What of the organs of speech in deaf and dumb persons? 475. What is said of the sounds produced by inferior animals? Upon what does the modification of these sounds depend? What is said of the cat and horse? What of howling animals?

476. **Birds** are furnished with two larynx, a superior and inferior, which serve at the same time for the entrance and exit of air, and for the purposes of vocalization. The upper larynx, which corresponds to the larynx in mammifers, can only be regarded as an accessory of the voice. The lower larynx is the true larynx; it is placed at the lower part of the trachea, where it branches. Those birds in which it is absent are voiceless. The voice of birds is produced like that of mammifers, by the vibration of the cords of the glottis.

477. **Insects** in general, produce sounds remarkable for their acuteness. Their sounds are produced in a great number of ways, some effecting it by percussion, and some by the friction of exterior horny organs upon each other, as, for example, in the grass-hopper. In others, the swiftly recurring beatings of the wings produce sounds, as with the musquito. Many insects produce sound by the action of some of their organs on the bodies around them, as, for example, the various insects which gnaw wood.

THE EAR.

478. **Auditory apparatus of man.**—In the ear, impressions are not at once made upon the sensory nerve, by the body which originates the sensation, but they are propagated to it, through a medium capable of transmitting them. This medium is the atmospheric air.

The organ of hearing in man is composed of three parts; the external ear, the middle ear, or tympanum, and the internal ear, or labyrinth.

479. **The external ear** consists of (1) the pinna, or pavilion, *a*, fig. 291, which collects the soniferous rays, and directs them into (2) the auditory canal, or meatus auditorius, *b*.

The peculiar form of the pinna, with its numerous elevations and depressions, has not as yet been satisfactorily shown to be related to the principles of acoustics.

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476. What is said of voice in birds? What of the lower larynx? What of voiceless birds? 477. What is said of the sounds produced by insects? How are they produced? 478. What is said of the ear? Of what parts is the ear composed? 479. Of what does the external ear consist? What is said of the pinna? What of the tympanum?

The auditory canal proceeds inwards from the pinna, to the tympanum, *c*; it is an elliptical tube, about an inch long. Its interior is protected by hairs, and by a waxy secretion.

480. **The middle ear, tympanum, or tympanic cavity.**—The

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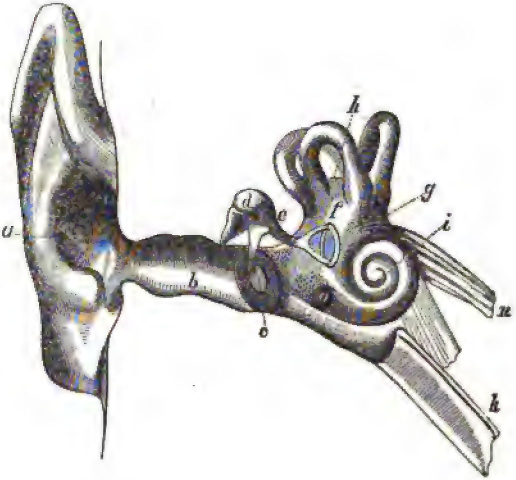

middle ear is a cavity in the petrous bone, and is, therefore, surrounded by walls of bone, (which have been removed in fig. 292, to show the interior construction.) This cavity, which is filled with air, is somewhat hemispherical in form; it measures about half an inch in every direction. The auditory canal is directed into this cavity, but is separated from it by a thin oval membrane, the tympanic membrane, which is placed obliquely across the end of the canal, and at an angle of about 45°; its outward plane looking downwards.

Into the tympanic cavity there are ten openings. 1.—That of the auditory canal; 2, 3, the fenestra ovalis, and fenestra rotunda, so called from their form, situated opposite the auditory canal, and like it, over both are stretched thin elastic membranes. 4. The Eustachian tube, a membranous canal, which extends from the anterior of the tympanum to the pharynx, and forms part of the respiratory passage behind the mouth; its office is, like the hole

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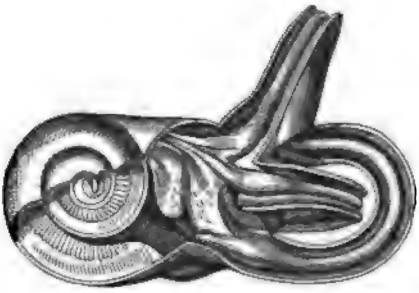
480. What is the middle ear? What is said of the tympanic membrane? What is said of the openings into the tympanic cavity? What is said of the chain of bones?

in a kettle drum, to preserve a permanent equilibrium between the air in the cavity, and the external air. When this is obstructed, deafness results, because the air in the tympanum is prevented from vibrating freely. 5.—The mastoid cells. The other openings are for the passage of various nerves and muscles.

292



The tympanum is crossed by a chain of bones, three in number, fig. 293.

The malleus, or hammer bone, *m*, the incus, or anvil, *o*, and the stapes, or stirrup, *t*. They are connected with each other in such a manner as to allow of slight movements. This chain of bones is attached at one end, as is shown in fig. 291, by the handle of the malleus, to the tympanic membrane, and at the other by the foot of the stirrup, to the membrane of the fenestra ovalis.

The muscles which act upon these small bones are supposed to have the power of giving more or less tension to the membranes which they connect, and thus rendering them more or less sensitive to sonorous undulations.

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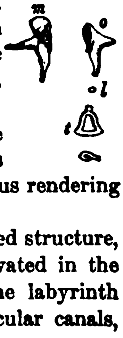

481. **The internal ear**, called, from its complicated structure, the labyrinth, has its channels curved and excavated in the petrous bone, the hardest of any in the body. The labyrinth consists of three parts; the vestibule, the semicircular canals, and the cochlea.

The vestibule, *g*, fig. 291, is a central chamber, excavated in the petrous bone; in it are a number of openings, for branches of the auditory nerve, small arteries, &c. In its external wall, the fenestra ovalis is found.

The semicircular canals are three in number, opening into the vestibule at its posterior and upper part, and placed in planes at

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What is said of the muscles that act upon these bones? 481. Of what does the labyrinth consist? What is the vestibule?

right angles to each other. Within these canals are placed flexible tubes, of the same form, called membranous canals.

The cochlea, *i*, is a conical tube, wound spirally, making two and a half turns. It resembles a snail's shell in appearance; whence its name. Its interior is divided by a spiral lamina, called the lamina spiralis, into two passages which communicate by a little hole in the upper part of the helix. Between the membranous and the bony labyrinths, a peculiar liquid (the perilymph) intervenes, which also fills the cavities and cochlea; the membranous labyrinth is distended by another liquid, (the endolymph.) Within the labyrinth thus filled with liquid, the terminal filaments of the auditory nerve are placed.

Fig. 292 is a magnified view of the labyrinth, showing the form and relation of the vestibule, semicircular canals and cochlea, partly laid open, so as to display their interior construction.

482. **Common theory of the function of the auditory parts.**—The explanation usually given of the functions of the various parts of the ear, is as follows. The waves of sound passing into the external ear, are collected and directed into the auditory canal, and strike upon the tympanic membrane, which is thrown into vibration. The chain of bones connecting the tympanic membrane with the oval one, participate in the movement, and convey it across the tympanic cavity. Under the impulses thus communicated to it, the oval membrane vibrates, and likewise the liquid in the labyrinth, and so the filaments of the auditory nerve become affected, and the sensation of sound is transmitted to the brain.

This explanation is exceedingly imperfect, as it assigns no use for many of the most complicated and delicate arrangements of the ear, and gives no explanation of the manner in which this organ presents to the mind the various relations of sound.

483. **Function of the drum, cochlea, and canals.**—As has been stated, (443-46,) the physical peculiarities existing in the waves of sound, which we are able to perceive, are three; 1st.—The intensity, namely, the loudness or feebleness of the sound. 2d.—Its note or pitch, and 3d.—Its timbre or quality.

The ear, it is apparent, is affected by each of these peculiarities,

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What are the semicircular canals? What is the cochlea? 482. What is the common theory of the function of the auditory parts? What is said of this explanation? 483. What are the physical peculiarities of sound?

and conveys them to our mind. Dr. Draper, in his Human Physiology, has suggested the following points, which may or may not be confirmed. 1st.—That the drum is for the measurement of intensity. 2d.—The cochlea for the recognition of wave-length, or pitch; and 3d.—The semicircular canals for the appreciation of quality.

It has been proved by the experiments of Savart and Müller, that when the tension of the tympanic membrane is increased, the sonorous undulations pass with less readiness through it. Under natural circumstances, this is accomplished by a muscle, (the tensor tympani,) which contracts it to such an extent as to bring the membrane to a standard tension. The mind judges of the degree of force necessary to produce this result, and so estimates the intensity of sound.

The first third of the spiral lamina contained in the cochlea, is bone, the intermediate portion is membranous, and the residual, muscular. This lamina is broadest at the bony part, the base, and tapers off toward the apex, reminding one of the structure of the harp, or the gradually shortening strings of the piano. It is supposed that each external musical note does not throw the lamina of the cochlea into vibration throughout its whole length, but causes only a special part to vibrate; thereby, the particular nerve fibril supplying that portion, is affected, and thus a distinct sensation is communicated to the brain, corresponding to the pitch of the note.

As the intensity of sounds is assumed to be judged of by the tympanum, and their pitch by the cochlea, there is a strong presumption that the semicircular canals have the function of distinguishing their quality. So little is known, however, of the mechanical peculiarities on which distinctions of quality in sounds depend, that we cannot trace out the form of the organ calculated to distinguish them. The presumption that the function of the semicircular canals is for the appreciation of quality, is strengthened by facts drawn from comparative physiology. Let us therefore examine the—

484. **Organs of hearing in the lower animals.**—The zoophytes appear to be wanting in the sense of hearing, and no special auditory apparatus has been discovered in insects, although they do not appear to be altogether insensible to sound. In the mollusca, the organ is a sack, filled with the liquid, in which the last fibrils of the acoustic nerve are diffused, or a nerve fibril, in connection with a little stony body, (an otolith,) included in a sack

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What office does Dr. Draper assign to each part of the ear? How is the tension of the tympanic membrane increased? What is said of the vibration of the laminae of the cochlea by musical notes? 484. What is said of the zoophytes? What of the mollusca? What of lizards?

of water. These animals can only distinguish one noise from another, or their quality, and that imperfectly, and have no perception of musical notes. This organ, corresponding, as is assumed, to the semicircular canals, increases in complexity as we rise in the scale of being. In lizards and scaly serpents, the ear commences with the tympanic membrane; and there is added a conical cochlea. As we pass through them, the plan is further developed; the tympanic cavity, Eustachian tube, the chain of bones, &c., appear. In birds there is a continued improvement, and all the aerial tubes of mammals have external ears, while a full development of all the auditory parts is reached only in man.

PHYSICS OF IMPONDERABLE AGENTS.

485. We have been occupied, hitherto, with the consideration of those topics connected with the forces of attraction and repulsion, as manifested in the form and other sensible properties of matter, at rest, or in motion. These forces have been already defined, (29 and 30,) and limited. It now remains to consider certain other remarkable forces called HEAT, LIGHT, and ELECTRICITY, and commonly styled the IMPONDERABLE AGENTS, because the presence or absence of their manifestations causes no sensible difference in the weight of matter containing them.

HEAT.

1.—*General Remarks.*

486. **What is heat?**—Heat is the agent whose presence or absence awakens in us the sensation of warmth or coldness.

The three physical states of matter, namely, the solid, liquid, and gaseous, (38,) are due to this agent. Like all other physical agents, it is manifested and measured by its effects upon matter. While we call it an imponderable agent, it is, so far as we know, inseparably connected with changes in the physical and chemical condition of matter. Heat is properly a species of motion.

487. **Definition of terms.**—1st.—*Expansion*, the most conspicuous effect of heat upon a body, whether solid, fluid, or gas-

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What is said of birds, &c.? 485. What subjects have been hitherto discussed? What forces now remain to be considered? 486. What is heat? What depends on it? How is it manifested? With what is heat connected? What may it be?

eous, is seen in the increase of all the dimensions of the thing heated. 2d.—*Contraction*, the opposite effect to expansion, results from the loss of heat. By the use of these changes of dimensions, heat is measured. 3d.—*Liquefaction* and *vaporization*, are changes of physical condition, due to the successive additions of heat to matter; the subsequent withdrawal of which heat produces. 4th.—*Condensation*, or liquefaction, and *congelation*, or solidification. 5th.—*Sensible* heat is that temperature whose presence or absence is marked by the senses, or by the thermometer, and, 6th.—*Latent*, or concealed heat is that which is so combined with the matter containing it, as to give no sensible evidence of its presence. 7th.—*Specific* heat is the amount of heat needed to raise any given body to a fixed standard temperature, which amount is found to be very various for different substances.

488. **Nature of heat.**—Various opinions have been entertained as to the nature of heat, only two of which now merit attention. These are the *corpuscular* theory, or *theory of emission*, and the *undulatory theory*.

According to the corpuscular theory, heat is attributed to a peculiar imponderable fluid, existing in all bodies in combination with their atoms. The particles of this supposed fluid are self-repellant, and thus the atoms of bodies are prevented from coming in absolute contact with each other. This fluid is thrown off from all hot bodies with inconceivable velocity, and upon its absorption by other bodies the effects of heat are manifested.

In the undulatory theory, heat is considered to be due to the vibratory movements of the molecules of a hot body, communicated to those of other bodies, by means of a highly elastic fluid called *ether*. This ether pervades all space, and in it the undulations of heat, (and of light also,) are propagated with inconceivable rapidity, in a manner analogous to the slower progress of sonorous waves in air, as already explained (412.) If these undulations are communicated to a cold body, they render it warmer.

The undulatory theory is now generally adopted by physicists, and explains, satisfactorily, most of the phenomena of heat.

489. **Heat is imponderable.**—A great number of experiments

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487. Define the terms expansion, contraction, liquefaction, condensation, sensible heat, latent heat, and specific heat. 488. What two theories of heat are there? Define the corpuscular theory. What is the undulatory theory? Which is generally accepted? 489. Why is heat called an imponderable agent? Of what is it an attribute?

have been made to ascertain whether heat increases the weight of bodies. The result arrived at is, that a body weighs exactly the same when hot as when cold. Heat is therefore called an *imponderable* agent, being, as before stated, only an attribute of matter in a certain state or condition.

490. **Relations of heat and cold.**—Our sensations give us but little evidence respecting actual changes of temperature. Hot and cold are only relative terms. A body will feel hot or cold, according to the temperature of the part to which it is applied, and slight differences of temperature are inappreciable to our senses.

If we place one hand in hot and the other in cold water, and then suddenly transfer both to water having an intermediate temperature, our sensations are at once reversed; one hand will feel warm, and the other cold, although both are exposed to the same temperature.

A deep cave, or a common cellar have nearly the same temperature at all seasons of the year, yet if one enters them on a warm day, they will feel cool, while on a frosty day the reverse is felt.

Heat and cold are merely relative terms; cold implying not a quality antagonistic to heat, but merely the absence of heat in a greater or less degree. There are no bodies so cold, that they will not be warm to bodies colder than themselves; and an absolute zero, or negation of heat, is impossible.

491. **Sources of heat.**—The sources of heat may be classified as follows:

1st.—*Mechanical.*—Every arrest of motion produces heat. The blows of a hammer actively applied, will heat a small bar of iron to redness. The friction of the flint ignites the small chips of steel torn off by the blow. Savages kindle fires by the friction of two dry boughs; and boys know how to heat a button by rubbing it on a board. Water may be boiled by simple beating, and Rumford (in 1805) boiled water by the friction from boring a cannon. The mechanical equivalent of heat will be, hereafter, more fully considered. No necessary change of *chemical* condition accompanies mechanical heat.

2d.—*Physical.*—The sun is the great source of heat for our earth; and the fixed stars, (*suns of other systems,*) probably yield to space an equal amount of heat. Our earth, in past ages,

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490. What is said of the evidence of our senses respecting heat? Illustrate this. 491. What are the sources of heat? Describe, 1st, the mechanical causes of heat.

has radiated into space a large amount of heat for which no equivalent has been returned. This loss, (called secular refrigeration,) is now arrested, almost entirely, by the non-conducting nature of the earth's crust, confining the central heat. But we have abundant evidence of a progressive increase of temperature toward the earth's centre, in deep mines and artesian borings. (251.) Atmospheric electricity is also a source of heat, as is evident from the effects of a powerful flash of lightning.

3d.—*Chemical.*—Heat is always evolved in chemical combination, as all common cases of combustion testify, and is limited to the quantities of matter whose condition is thus changed.

4th.—*Physiological.*—This source of heat is essentially chemical action, being combustion taking place under the influence of vitality. The temperature of living beings is, generally, greater than that of the medium in which they live.

These different sources of heat may be considered more at length hereafter.

2.—*Measurement of temperature.*

492. **Thermometers.**—All bodies expand when heated, and almost universally return to their original dimensions on cooling; the measured amount of this expansion is generally employed as a measure of the temperature.

The ordinary thermometer consists, essentially, of a glass tube with a small bore, having a bulb blown on one end. This bulb, or reservoir, and a part of the tube, is filled with a liquid, usually mercury, (sometimes for low temperatures spirits of wine,) which expands and rises in the tube by heat, and contracts and falls in the tube by cold. A scale of equal divisions, marked upon the tube, enables the amount of the expansion or contraction to be determined.

493. **What the thermometer indicates.**—The thermometer indicates only the sensible heat or temperature, and not the actual quantity of heat in a given case.

Two vessels filled with water from the same source, will raise the thermometer to the same degree, though one may hold a pint and the other a gallon; while it is evident that the larger bulk of liquid contains the greater aggregate amount of heat. Again, if two equal

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2d, the physical; 3d, the chemical; 4th, the physiological. 492. How is heat measured? Describe the ordinary thermometer. 493. What does the thermometer show? Illustrate this.

vessels are filled with water, one at a temperature of 100°, and the other at a temperature of 200°, it would be a mistake to suppose that the latter contained twice as much heat as the former, for the zero of the thermometer is an arbitrary point, and does not indicate the entire absence of heat.

494. **Thermometer tubes.**—The tube of which a thermometer is to be made, should be one whose bore, throughout, is of the same calibre, so that equal dimensions upon it, will indicate equal expansions of the mercury contained in the bulb. The equality of the bore is ascertained by causing a short cylinder of mercury, (say one inch,) to pass from end to end of the tube, and if it measures an equal length throughout, then the calibre is equal; otherwise the tube is rejected. A proper tube having been selected, a bulb (cylindrical or spherical) is blown upon it, by the ordinary process of glass blowing. A cylindrical bulb will be more readily affected by the temperature of the surrounding medium than a spherical one, because it exposes a larger surface.

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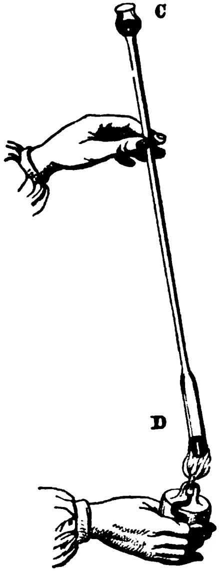

495. **Filling of thermometer tubes.**—To fill a thermometer tube with mercury, (which should be perfectly pure,) a portion is placed in the reservoir, *C*, fig. 294, and heat applied at the other extremity by a lamp.

As the air in the bulb, *D*, expands, a portion of it escapes through the mercury. If the tube is now cooled, the pressure of the external atmosphere will force the mercury into the bulb, *D*, partially filling it. Then upon boiling the mercury in the bulb, as shown in the figure, the mercurial vapor gradually expels the remaining air and moisture. Upon cooling again, the mercury, under atmospheric pressure, descends, and completely fills the bulb and stem. The reservoir, *C*, is then drawn out to a narrow neck, and broken off, preparatory to sealing the tube. If the

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494. What is requisite in thermometer tubes? How is a proper tube selected? 495. How is a thermometer tube filled with mercury? How is all the air and moisture expelled from the tube? How is it prepared for graduation?

tube had no reservoir of glass, a funnel of paper adapted to its upper end, will serve the same purpose. A greater or less portion of the mercury remaining in the stem, must now be removed, according as the thermometer is intended to indicate higher or lower temperatures. This is accomplished by gently heating the bulb, which causes the mercury to overflow the tube. When about two-thirds of the mercury contained in the stem has been driven out, and while the heat is continued in the bulb, the flame of a blow-pipe is directed upon the end of the stem, the glass melts, and the tube becomes hermetically sealed.

496. **Standard points in the thermometer.**—As variations in the height of the mercurial column in the thermometer will depend upon the changes of temperature to which it is subjected, it is therefore necessary to graduate the instrument, or construct a scale, whereby these variations may be indicated, and one thermometer compared with another. If there existed a natural zero, or absolute limit to temperature, the thermometric scale might be numbered upwards from it. But there is no natural zero, and therefore the thermometric scale must be arbitrary, although based upon certain well-determined physical facts. Experiment has determined that the melting point of ice, and the boiling point of pure water, under certain given conditions, are always the same, and these points, (called, respectively, the freezing and boiling points,) have been adopted in all countries as the two temperatures, with reference to which thermometric scales are constructed.

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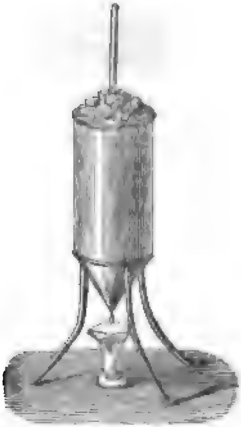

497. **Fixing of the freezing and boiling points.**—*Freezing point.*—To fix the freezing point in a thermometer, a tin vessel, like fig. 295, is filled with pounded ice or snow; a hole in the bottom of the vessel, allows the water from the melted ice to escape. Into this vessel the bulb of the thermometer is thrust, with part of the stem.

When the mercurial column becomes stationary, that is, when the

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496. How is a scale or standard of measurement obtained for graduating thermometers? What two fixed points are selected? Is there a natural zero? 497. How is the freezing point fixed?

mercury contained in the bulb has attained the temperature of the melting ice, the level of the mercury is marked with a diamond point, upon the glass, or with a pencil upon a paper previously attached to the tube; this marks the freezing point of the thermometer.

Boiling point.—By means of the apparatus, fig. 296, designed by Regnault, the boiling point may be accurately fixed. It is a cylindrical vessel of metal, *m*, closed at the top; through the cover a hole is pierced, over which the tube, *A*, is placed, open at both ends. Another tube, *B*, surrounds *A*, and in it there are three apertures, *a*, for the insertion of the thermometer, *E*, for a U shaped glass tube, *m*, containing mercury, acting as a manometer, to indicate the pressure or tension of the vapor within the apparatus; and, *D*, for the escape of the steam and condensed water. The vessel, *M*, partially filled with water, is heated to ebullition by the furnace, *C*. The steam that is produced, moves in the direction indicated by the arrows, upwards through the tube *A*, and downwards through the tube *B*, escaping, as water, through the spout *D*. The thermometer, by this means, is heated to the temperature of the steam, that is, to the temperature of boiling water. When the mercurial column becomes stationary, a mark is made at the level of the mercury, which indicates, therefore, the boiling point.

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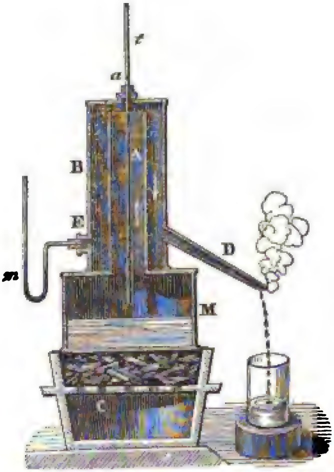

498. **Different thermometric scales.**—Having fixed the standard points in a thermometer, the space between them is next to be subdivided into a certain number of equal parts, called degrees. Unfortunately, in different countries, the interval between the two points has been differently subdivided.

Fahrenheit's scale.—Fahrenheit, of Dantzic, in 1714, introduced a thermometric scale, which is generally used in this country, England, and Holland. In the Fahrenheit scale, the in-

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How the boiling point? Describe the apparatus, fig. 296. 498. What thermometer scales are in use? Describe the Fahrenheit scale. How did Fahrenheit fix his zero? Why did he divide the space between zero and freezing into 32°?

terval between the boiling and freezing points, is divided into 180 equal parts, which are called degrees. The zero, or 0°, of this scale, is 32 of these degrees below the freezing point.

Fahrenheit adopted as the zero of his thermometer, the temperature which had been observed at Dantzic in 1709, and which he found he could always re-produce, by using a mixture of ice and salt. At that temperature he computed that his instrument contained 11·124 equal parts of mercury, which, when plunged into melting snow, were increased to 11·156 parts. Hence the space included between these two points, (viz., 11·156—11·124 = 32,) was divided into 32 equal parts, and 32° indicates, therefore, the freezing point of water. When the thermometer was plunged into boiling water, Fahrenheit estimated that the mercury was expanded to 11·336 parts, and therefore 212° (11·336 — 11·124 = 212,) was marked as the boiling point of that fluid. In practice, Fahrenheit determined the boiling point of water, and the melting point of ice, and then graduated the tube by equal divisions to his zero. To Fahrenheit belongs the merit of having introduced the use of mercury in thermometers, which had previously been made only with alcohol, water, or air.

Centigrade scale.—In the year 1742, the Swedish philosopher Celsius, professor at Upsal, introduced the centigrade scale. (Centigrade, means "100 degrees.") It is in general use for scientific purposes, and is adopted universally in France, and in the north and middle of Europe. The interval between the freezing and boiling points in this scale, is divided into 100 equal parts or degrees; the degrees being counted upwards and downwards, from the freezing point of water, which is zero. The temperatures below zero in this, as in all thermometers, are indicated by the negative algebraic sign —; those above, by the positive algebraic sign +; thus — 20°, signifies 20 degrees below zero, but + 20°, signifies 20 degrees above zero.

Reaumer's scale.—Reaumer, a French philosopher, introduced his scale in 1731. His proposal was to use spirits of wine, of such a strength, that between the two standard points, 1,000 parts should become 1,080. He divided the intervals between these points into 80 equal parts; the zero being placed at the freezing point of water. Reaumer's thermometer was the only one used in France before the great revolution (1789); it is still best known in Spain, and in some of the other European states.

Why did he make boiling water 212°? Who was Celsius? Why is his scale called *centigrade?* Describe it. What was Reaumer's scale founded on? How did he divide it?

499. **Conversion of the different thermometer scales into each other.**—The scale employed in a thermometer is indicated either by the name, or by one of the initial letters, F. C. R. The degrees of one scale may be converted into those of the others, by very simple calculations. Between the standard points in the Fahrenheit's thermometer, there are 180°; in the Centigrade 100°; and in the Reaumer, 80°; so that $1° \text{ F} = \frac{5}{9}° \text{ C} = \frac{4}{9}° \text{ R}$.

As the value of a degree in Fahrenheit's thermometer (498) is greater by 32 than the number of divisions from the freezing point, 32 must always be subtracted before the + degrees of Fahrenheit are converted into those of the other scales, and added upon the conversion of other degrees into Fahrenheit.

The following rules will be found useful for the conversion of the different thermometric degrees into each other.

To convert the degrees of Fahrenheit into those of Reaumer. Multiply the number of degrees, less 32, *by* 4, *and divide by* 9.

Example: What is 149° F. equivalent to in Reaumer's scale? (149— 32 =) 117 × 4 = 468, and 468 ÷ 9 = 52° R.

To convert the degrees of Reaumer into Fahrenheit, multiply the number of degrees by 9, *divide by* 4, *and add* 32.

Example: What is 36° R. equivalent to in Fahrenheit's scale? (36 × 9 =) 324 ÷ 4 = 81, and 81 + 32 = 113° F.

To convert the degrees of Fahrenheit into their Centigrade equivalent. Multiply the number of degrees, less 32, *by* 5, *and divide by* 9.

Thus, 212° F. is equivalent to 1,00° C., for (212 — 32 =) 180 × 5 = 900, and 900 ÷ 9 = 100.

To convert Centigrade degrees into those of Fahrenheit, multiply by 9, *divide by* 5, *and add* 32.

Example: What is 50° C. equivalent to in Fahrenheit's scale? (50 × 9 =) 450 ÷ 5 = 90, and 90 × 32 = 122° F.

500. **Graduation of thermometers.**—*Thermometers with regular bore.*—If the bore of the thermometer is regular, it is only necessary to divide the space between the boiling and freezing points into a certain number of equal parts, according to the

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499. How are these different scales distinguished? How are they connected with each other? Give the rules and examples in the three cases.

thermometric scale adopted, 180 for F; 100 parts for C; and 80 for R., continuing the equal divisions above and below the standard points, as far as may be desired.

Thermometers with irregular bore.—In order to graduate a thermometer whose bore is irregular, it is first divided into parts of equal capacity in the manner already indicated.

Supposing the number of these parts between the freezing and the boiling points was 16, each division would answer, if a Fahrenheit thermometer was being constructed, to 11·°25 ($180 \div 16 = 11{\cdot}25$.) It is assumed that each of these divisions is regular throughout its length; it must be nearly so; and it may, therefore, be sub-divided into any convenient number of equal parts; 11 for example. In this case the value of each subdivision would be 1°·0227, ($11{\cdot}25 \div 11 = 1{\cdot}0227 +$) The scale may be extended above and below the standard points, by pursuing a similar course.

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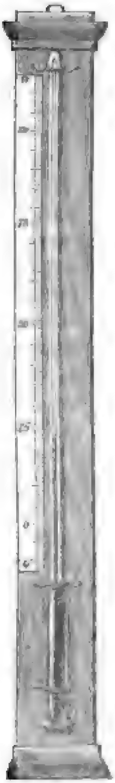

501. Mounting thermometers.—In ordinary instruments, the thermometer is supported by a brass plate, inclosed in a metallic case, open in front. On the plate the degrees are marked. Often the temperatures of *summer heat*, *blood heat*, and *fever heat*, are indicated by these words, placed opposite the points, 68°, 98°, 108°. A wooden frame often incloses and supports the thermometer, and the scale is marked directly upon the wood, or upon a metal, ivory, or porcelain strip attached to the wood at the side of the thermometer, as in fig. 297.

Other thermometers have their graduated wooden support, divided near the lower end into two parts, connected together by a hinge, so that the lower part may be turned back, and the bulb thrust into any liquid whose temperature it is desired to ascertain.

Some thermometers have their stem very small, and completely surrounded by a larger tube; the scale, being marked upon a porcelain strip, or a roll of paper, inserted between the two tubes.

In very accurate thermometers, the scale is marked upon the tube

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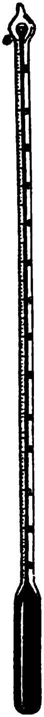
500. How are thermometers graduated? How if the bore is irregular? 501. How are thermometers mounted? How are they fitted for hot or acid fluids? How are very accurate thermometers marked?

itself, (by means of hydrofluoric acid,) as in fig. 298. This form presents advantages over all others, as the scale cannot become displaced, and its length remains constant, while in other thermometers, and especially those with metallic scales, the unequal expansions and contractions of the glass and metal, are a source of error. At the top is a small reservoir, *a*, to allow space for the mercury, in case of any unusual expansion, which might otherwise burst the glass.

298



502. **Displacement of the zero point.**—If a thermometer which has been made some time is thrust into melting ice, the column of mercury will not sink to the original freezing point, but will remain at a distance above it, sometimes as much as two or three degrees, and even more. M. Legrand has found that the cause of this change is, that the capacity of the reservoir is enlarged at a high temperature, (as during the construction of the thermometer,) and that it does not return to its original dimensions until after a long time, sometimes not until after two or three years.

Before making important observations therefore, thermometers should be examined as to the position of their freezing point. M. Regnault has found that thermometers made of different kinds of glass, which agree at the freezing and boiling points, may vary at intermediate temperatures a number of degrees, owing to the different expansions of the sort of glass of which they are composed.

503. **Tests of a good thermometer.**—In order to ascertain whether a thermometer is correct or not, it is first plunged into melting ice, and then into boiling water; the level of the mercury should indicate upon the scale exactly 32°, and 212° F. When inverted, the mercury should fall with a sudden click, and fill the tube, thus showing the perfect exclusion of air.

To determine whether the value of the degrees is uniform, a slight jerk is given to the thermometer, by which a little cylinder of mercury is detached from the column. On moving the little column through the tube, it should occupy equal spaces in all parts, if the bore is perfectly accurate, and the scale is properly graduated.

What advantages has this form? 502. How is an error in the zero point likely to happen? What precaution is suggested? 503. What are the tests of a good thermometer?

504. **Sensibility of thermometers.**—The sensibility of a thermometer is of two kinds; it may indicate very small *differences*, or it may be very sensitive to *changes* of temperature.

If the capacity of the reservoir is large, compared with the bore of the tube, a slight change of temperature will affect, considerably, the height of the mercurial column. If the capacity of the reservoir is small, the mercury contained in it will be *more rapidly* affected by such changes, than if a larger amount were to be acted upon. A cylindrical reservoir is, therefore, better than a spherical one, because it exposes a larger surface.

The two kinds of sensibility indicated, are obtained in a thermometer which has a small cylindrical reservoir and a very capillary tube.

505. **Limits of the mercurial thermometer.**—Mercury is by far the most available thermometric fluid. It may easily be obtained pure; it does not adhere to the sides of the tube, and above all, it has a greater range of temperature, between its freezing and boiling points, than any other liquid; freezing at —39°·2, and boiling at 662° F. Between these two points, its expansion for equal increments of heat is very regular, excepting near its freezing point. Owing to this last irregularity, mercurial thermometers cannot be accurately used for temperatures lower than —33°. Above the boiling point of mercury, heat is measured by instruments called pyrometers, (517.) For very low temperatures, spirit of wine thermometers are employed.

506. **Spirit thermometers; other liquid thermometers.**—Alcohol has never been frozen, and is, therefore, used for the estimation of low temperatures. Thermometer tubes are filled with alcohol, (which is generally colored red,) by heating the bulb, with the open end of the tube thrust into alcohol, and completing the process in the manner already indicated. (495.) The tube is graduated by comparison with an accurate mercurial thermometer, exposing both to the same temperature, and marking, successively, upon the alcoholic thermometer, the temperatures indicated by the mercurial thermometer as they are gradually heated. The alcoholic thermometer should not be divided into

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504. What is said of sensibility in thermometers? What forms of reservoir are preferred? 505. What peculiar excellences has mercury for thermometers? What limits? What is said of very low temperatures? 506. How are spirit thermometers constructed? How graduated? What liability of error is there in them?

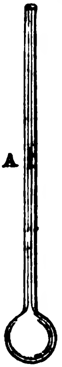
equal parts, between the freezing point of water and its boiling point, because it expands unequally, for equal increments of heat. Alcoholic thermometers often differ much from each other, because there is great difficulty in obtaining alcohol perfectly pure, or of exactly the same degree of concentration.

Capt. Parry, in his arctic voyages, (whose experience was confirmed by Dr. Kane, Arct. Exp. II, 405,) found a difference of 18° F., between alcoholic thermometers constructed by the most celebrated makers; and a difference of 14° F., has been observed, even at a temperature of only 15°, or 20° F. In consequence of this, other liquids have been proposed for thermometers, intended to indicate low temperatures. From the experiments of M. Pierre, of all liquids, ordinary sulphuric ether, clorid of ethyle, and bromid of methyle, were found to be best adapted for such instruments.

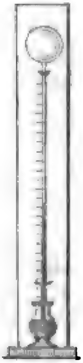
507. **Air thermometers.**—As air contracts uniformly and quickly, it is sometimes used in thermometers, where slight and sudden variations of temperature are to be observed. The contractions and expansions which it undergoes, are rendered visible by the movements that it causes in liquids.

The simplest air thermometer is that represented by fig. 299. It is a bulbed tube, filled with air, having for an index a drop of colored liquid in the stem at *A*. The movements of the index show the variations of temperature. Another thermometer, often called Sanctorio's thermometer, is represented by fig. 300. The extremity of the tube rests in the colored liquid contained in the open vessel. If the bulb is heated, the liquid falls in the tube, and rises if the bulb is cooled.

299



300



Amontons' thermometer, fig. 301, is essentially the same as the last; the bulb, *C*, is partially filled with colored liquid. Expansion of the air contained in the upper part of the bulb, *C*, causes the liquid to rise in the tube *A B*.

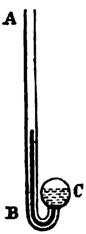
These instruments are necessarily imperfect, owing to the varying pressure of the atmosphere, and they serve only as means for the illustration of principles in the class-room.

Illustrate this from arctic experience. 507. What is said of air thermometers? For what are they used? What is Sanctorio's thermometer? What is Amontons' thermometer?

508. **History of the thermometer.**—It is not certain to whom we are indebted for the discovery of the thermometer. This honor is attributed, generally, to Cornelius Drebbel, who, some say, was a peasant of North Holland, others, that he was a physician of Alkmaar. Italian writers generally give the credit to Santorio Sanctorio, who flourished at the beginning of the 17th century. It is by no means improbable, that each may be justly entitled to the merits of its invention.

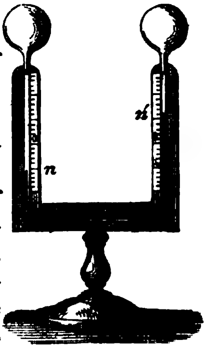
These early thermometers indicated temperatures by the expansion of air; the first great improvement was made by the Florentine academicians, who substituted spirits of wine for the purpose. They divided the instrument arbitrarily, as before, by little dots of enamel, placed at equal distances upon the tube.

301



Fahrenheit (died 1736) employed mercury in thermometers in 1720. By some, this discovery is given to Reaumer, a philosopher of France, who died in 1757. Newton used linseed oil. Renaldi, at the close of the 17th century, proposed the melting of ice as a fixed point on the scale. Newton marked this point 0°, and took for other points, the temperature of the blood of man, (marking it 12°,) and the temperature of boiling water, (marking it 34°.) Celsius, in 1741, adopted the melting of ice and the boiling of water, as the two standard points of the scale, and divided it into 100 parts. From this time the thermometer received numerous improvements, until now it has attained as high a degree of perfection as almost any philosophical instrument.

302



509. **Leslie's differential thermometer.**—This instrument, fig. 302, consists of a tube, bent twice at right angles, upon each end of which is a bulb. Within the tube is a portion of sulphuric acid, colored red. When both bulbs are subjected to the same temperature, the liquid column will be at the same height in both tubes. If one bulb is heated, the air expanding will drive the liquid in the stem toward

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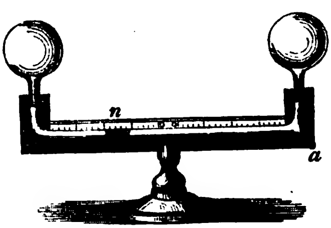
508. Who are the rival claimants for the honor of discovery of the thermometer? Who first used fluids in the place of air? When was mercury first used in thermometers, and by whom? Give other points in the history of this instrument. 509. Describe Leslie's differential thermometer. Why is it so called?

the other bulb, as seen in the figure at *n n′*. It is evident that this instrument does not indicate general changes of temperature, but only differences between the temperature of the two bulbs. In a limited number of cases, it furnishes an instrument of great delicacy and utility, and is the only form of air thermometer of any scientific value. Almost identical with this, is—

510. **Rumford's thermoscope.**—At the same time that Leslie invented his differential thermometer, Count Rumford, (otherwise Benjamin Thompson,) an American by birth, brought forward a very similar apparatus, called a thermoscope, represented in fig. 303.

The horizontal tube is longer, and the bulbs larger, than in the preceding instrument. In the horizontal tube is placed a drop of sulphuric acid, *n*, which serves as an index, and separates the two volumes of air. When the instrument is in equilibrium, the index remains at the centre of the horizontal tube, and changes its position as the temperature of the two bulbs varies.

303



511. **Rutherford's maximum and minimum thermometers.**—It is often desirable to ascertain, in the absence of an observer, the highest and lowest temperature of the night, or of any other interval of time. This may be done by the employment of what are called maximum and minimum, or self-registering thermometers. One of the most simple instruments of this kind was invented by Rutherford, and is represented in fig. 304.

It consists of two thermometers attached to a plate of glass, or to wood; their tubes are bent at right angles, near the bulbs. The maximum thermometer, *A*, contains mercury; the minimum thermometer, *B*, contains alcohol. In the tube of the former is a small piece of steel, (seen at *A*;) when the mercury expands, it pushes the steel before it, but when the fluid recedes toward the bulb, the wire does not follow it. The steel is thus left at the extreme point to which the mercury may have moved it, and indicates the highest, or maximum temperature, to which it has been exposed. The alcoholic thermometer contains a small piece of enamel, (seen at *B*,) sunk

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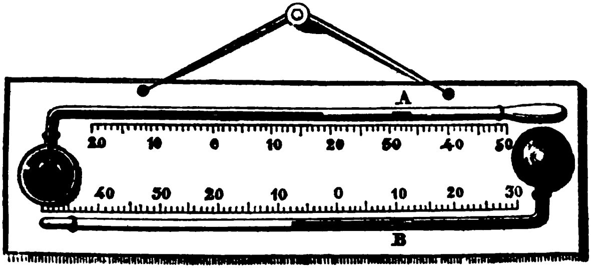
510. What is Rumford's instrument? Describe it. 511. What are maxima and minima thermometers? Describe Rutherford's instrument, fig. 304.

below the surface of the liquid. The position of the enamel is not affected by expansion, because the alcohol readily passes it; but on contracting, it is drawn back with the column of alcohol, because it cannot overcome the cohesive attraction of the particles

304

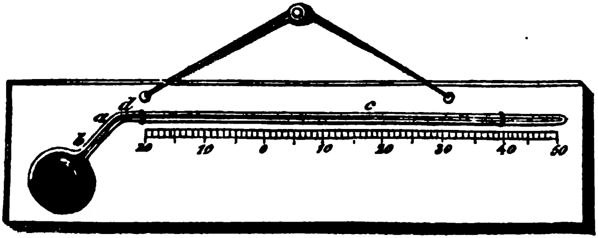


of liquid at the surface of the column. Thus the enamel is left at the lowest point to which the column has retreated, and represents, therefore, the minimum temperature which has occurred.

512. **Negretti and Zambra's maximum thermometer.**—A slight agitation given to Rutherford's maximum thermometer will often cause the steel index to become immersed in the mercury, which, upon expansion, will pass by the steel, and thus the instrument will fail to fulfill the purpose for which it was designed. This source of error is avoided in the use of Negretti and Zambra's instrument, fig. 305.

A small rod of glass, *a b*, is introduced into the thermometer tube,

305



which is then bent just above the point where the rod is placed; the rod nearly fills the bore of the tube. When in use, the instrument

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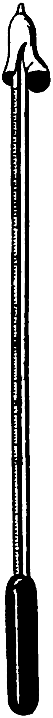
How are its indications recorded? 512. What fault of the last is avoided in the instrument, fig. 305? What is it called?

is suspended horizontally. The mercury, by expanding, will force its way past the obstruction, to the point, *c*, for example; when the temperature falls, and the mercury contracts, the cohesion of the particles of mercury to each other will prevent the column from passing the rod. The extremity of the column, *c*, will therefore indicate the highest temperature to which the instrument has been exposed.

306



513. **Walferdin's maximum thermometer.**—The upper part of the tube of this instrument, fig. 306, terminating with a small orifice, is surrounded by a reservoir which contains mercury. When the instrument is to be used, it is first heated, whereby the mercury rises in the tube and overflows into the reservoir; it is then inverted. The elongated point of the tube thus dips into the mercury of the reservoir. It is now exposed, while inverted, to a lower temperature than the one to be determined. During this cooling, the tube will remain full because its point dips into the reservoir of mercury. The instrument is now placed in its proper position, and it is evident that as the temperature rises, a portion of mercury will pass out of the full tube into the reservoir; and the portion will be greater as the temperature is higher.

To determine afterwards the highest temperature to which it has been exposed, it is compared with a standard thermometer. Both being placed in a water bath, gradually heated, and observing the temperature indicated by the standard thermometer, when the mercurial column has risen to the top of the tube of the maximum thermometer.

514. **Metastatic thermometer.**—M. Walferdin has also invented a thermometer designed to indicate very small differences of temperature. In this instrument, fig. 307, the reservoir, and calibre of the tube, are very small.

There is a bulb, *B*, in the upper part of the tube, containing a small quantity of mercury. Just below this bulb, the capillary tube suddenly contracts at *C*. The scale is entirely arbitrary, consisting of the division of the tube into parts of equal capacity. In using this thermometer, it is first heated to a temperature somewhat higher than the one it is wished to estimate. The mercury rises in the tube and partially fills the bulb. A slight

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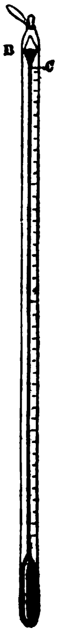
How is it constructed and used? 513. Describe Walferdin's maximum thermometer. How is this used? 514. What is the metastatic thermometer?

shake given to the instrument while cooling, causes the mercurial column to break at the point of contraction, and while a portion of mercury remains in the bulb, the mercurial column sinks down to a point somewhere above the reservoir. The thermometer must now be exposed to a known temperature, very near to that we wish to estimate; when the position of the level of the mercury in the tube is noted. The thermometer is then subjected to the medium, whose temperature is to be estimated. If there is a difference in the level of the mercurial column in the two cases, of 18 divisions of the scale, and if 300 of these divisions are equal to one degree, then the difference in temperature must be $\frac{18}{300}$ of a degree. M. Walferdin has employed thermometers which indicated one one-hundredth ($\frac{1}{100}$,) and even one one-thousandth ($\frac{1}{1000}$) of a degree, centigrade. ($\frac{1}{55}$ and $\frac{1}{555}$ of a degree F.) By causing more or less mercury to flow into the upper bulb, differences in temperature, more or less minute, may be estimated. A single thermometer of this description may take the place of a series of thermometers with a fractional scale.

307



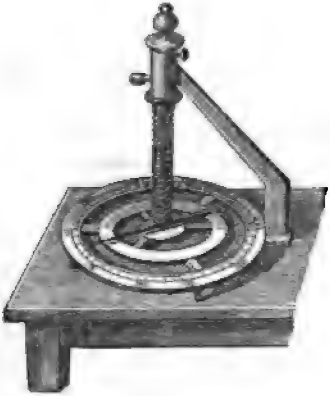
515. **Breguet's metallic thermometer.**—This instrument, remarkable for the extreme sensibility of its indications, depends upon the unequal expansion of different metals; it is represented in fig. 308.

Three strips of platinum, gold and silver, after being soldered together throughout their whole length, are rolled into a thin ribbon, which is then formed into a spiral, or a helix. The upper extremity of this helix is fixed to a support, and to the lower end, at right angles to it, is attached a needle, moving over a graduated circle, resembling the dial of a watch. The silver, which is the most expansible of the three metals, forms the inner face of the helix; the platinum, which is the least expansible, forms the outer face, and the gold, which has an intermediate expansibility, is included between them, and moderates their effects. When the temperature rises, the silver, expanding more than the other metals, unrolls the helix; the contrary effect takes place when the temperature is lowered. This thermometer is graduated by comparison with a standard mercurial thermometer. The instrument is particularly useful when very rapid variations of temperature are to be determined. Another form is sometimes given to it.

For what are they used? How minute differences of temperature do they indicate? 515. What is Breguet's metallic thermometer? Describe its construction. When is it peculiarly useful?

The compound ribbon, being bent into the form of a letter U, one of the extremities is fixed, and the other is left free to move. By means of a lever and toothed wheels, the movements which changes of temperature cause in the free end, are communicated to a pointer, moving over a dial.

308



516. **Saxton's deep sea thermometer.**—Mr. Joseph Saxton, of the U. S. Coast Survey, has adapted the principle of Breguet's metallic thermometer, in the construction of an instrument by which numerous very accurate observations have been made upon the temperature of the sea in deep soundings. Silver and platinum form the compound spiral, and its torsion is registered by an index, moved by multiplying wheels, and carrying forward a tell-tale, or stop-hand, to the lowest temperature attained. This instrument has been some years in use for deep sea soundings, with the best results.

517. **Wedgewood's pyrometer.**—The range of the mercurial thermometer is limited by the boiling point of mercury; higher temperatures are measured by the effects of heat upon solids with instruments called pyrometers.

The celebrated English potter, Wedgewood, invented the first pyrometer used. This was founded upon the *contraction* which clay undergoes when exposed to high temperatures. He assumed this contraction to be as much greater as the temperature was higher. The results obtained with this instrument are, however, inaccurate, as it is now known that the contraction which clay undergoes, depends rather on the duration than on the intensity of the heat, and is much modified by the particular sort of clay employed.

Fig. 309, shows the form of Wedgewood's pyrometer, consisting of three copper bars, each six inches long, firmly attached to a brass plate,

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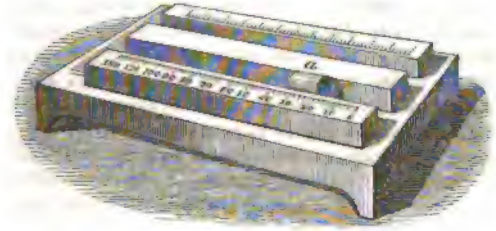
516. What is Saxton's deep sea thermometer? 517. What are pyrometers? What was Wedgewood's instrument? Why is it inaccurate?

with the space between them converging regularly from zero, (0°,) where it is half an inch, (6 lines,) to 4 lines, ($\frac{4}{12}$ths of an inch,) at the smaller end of the second couple. This space was divided into 240°

309



degrees—the 0° corresponding to 1000° Fahrenheit, each degree being about equal to 100° Fahrenheit. Small cylinders of clay, *a*, dried at 212°, and turned exactly to fit the larger end of the groove, were subjected to the temperature to be estimated, say that of a melting metal; contraction of the clay followed, and when cold, the test cylinder was slipped into the groove, until it met its own gauge, when the degree opposite recorded the temperature to which the clay had been subjected. Owing to the causes of inaccuracy already indicated, this instrument has now only a historical interest.

518. **Daniell's pyrometer** is the only instrument hitherto contrived capable of giving exact results for high temperatures.

This instrument fig. 310, consists, essentially, of two parts; the register, (1,) and the scale, (2.) The register is a case of black lead earthenware, *D D*, seven-tenths of an inch square, and eight inches long, in which is bored a cylindrical hole, seven and a half inches deep, and three-tenths of an inch in diameter. Into this cavity fits a rod of platinum, (or iron,) six and a half inches long, and a little smaller than the hole, and over it rests a plug, or cylinder, of hard porcelain, *o*, one and a half inches long, and confined snugly in its place by the strap of platinum, *r*, and a wedge of porcelain, *s*. This system may be exposed to the highest temperature of the most powerful furnaces, without injury to any of its parts, and the single effect of the heat will be to force forward (by the expansion of the metallic bar,) the plug of porcelain, as much as the bar has elongated beyond the expansion of the outer case, *D D*. To measure the exact amount of this expansion is the object of the scale,

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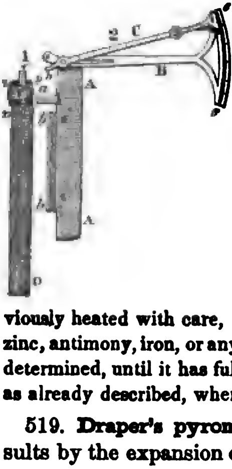
518. What is Daniell's pyrometer? Describe the register. Describe the scale. How is an observation made with it? How are the degrees of measurement converted into degrees of temperature?

(2,) fig. 310. Before the experiment, the black lead register has been nicely adapted to the edge of the brass rule, *A A*, and of its attached gauges, *a* and *b b*, (the shoulder of *D D* fitting under *a*.) In this position the point *h*, on the shorter limb of the movable arm *C*, fits into an indentation *t*, on top of the porcelain cylinder. The nonius *g*, then reads 0°, on the graduated arc *e e*. The distance from the centre to *h*, is just one-tenth of the distance to *g*. After the experiment, the register being adapted as before, the nonius moves forward on the graduated arc in proportion to the expansion of the bar, *o*. Since the expansion is directly as the temperature, it remains only to convert degrees of arc into degrees of temperature. The scale, *e e*, is so adjusted with reference to other parts of the instrument, that the arc read off may be converted into decimals of an inch of expansion, by seeking, (in a table of natural sines,) the sine of half the observed arc, and reading it as the decimal of an inch. The relation of this instrument to the common thermometer, was determined by subjecting cylinders of platinum and iron in it, to the known temperatures of boiling water and mercury, successively, and from the measures thus obtained, fixing a ratio between degrees of expansion and of temperature.

310



In use, the case, *D D*, (with its rod,) previously heated with care, is plunged into a crucible containing melted zinc, antimony, iron, or any other melted metal whose temperature is to be determined, until it has fully the same temperature, and then reading off as already described, when the whole had become quite cool.

519. **Draper's pyrometer.**—This instrument registers its results by the expansion of a little strip of platinum, heated (in free air) by a measured current of voltaic electricity.

The platinum strip is connected with the short end of a lever, whose longer limb marks upon a graduated arc the degree of expansion. With this delicate instrument, Prof. Draper conducted a series of experiments upon the temperatures at which bodies become visibly red, in the dark and in diffused light, the temperatures being determined from the co-efficient of expansion in the several metals. (Silliman's Journal, [2] iv. 388.)

The term pyrometer is sometimes applied to instruments in-

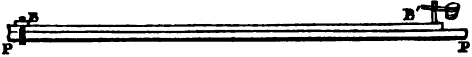
How is the relation to the common thermometer established? 519. What is Draper's instrument? How is the term pyrometer sometimes used?

tended to measure changes of dimensions in bodies at low temperatures by the expansion of solid rods; such is—

520. **Saxton's reflecting pyrometer.**—In the measurement of the long base lines of the larger triangles, in the survey of the coast of the U. S.; lines sometimes forty or fifty miles in length, the greatest accuracy is requisite. The measuring rods contrived for this purpose by Prof. Bache, are compound bars of iron and brass, so proportioned in their cross section as to equalize their differences of specific heat and conductibility, while their unequal expansions compensate for each other, and preserve an invariable length. To verify these bars, the ends are brought in contact with two blunt knife edges; one immovable, the other forming the shorter end of a compound lever; having at the other end a rotating mirror. Any variation of length in the bar, by changing the angular position of the mirror, gives evidence of the change to an observer, whose eye is placed at a telescope directed towards the mirror, in which the one twenty-five thousandth of an inch on a scale is magnified into a unit of graduation, about one-fourth of an inch long, from which the one hundred-thousandth of an inch, or about one four-millionth of a metre is easily read. If desirable, this degree of minuteness might be greatly increased. This simple and beautiful contrivance, has superseded all methods previously known, for verifying rods of any length. It is sensibly affected in bars six metres long, by changes of temperature otherwise quite inappreciable, and it then becomes the most sensitive of thermometers. This method is good only for end measurement.

Borda's method of verification, (adopted in the measurement of an arc of meridian, by which the unit of the French standard measures was determined,) consisted in the employment of a bar of platinum, *P P*, fig. 311, and one of brass, *B B'*. These were firmly clamped at one end, *B*, while at the other a finely divided scale and vernier gave the means of reading the variations in length of the bars by a microscope. A variation of 1° C., was

311



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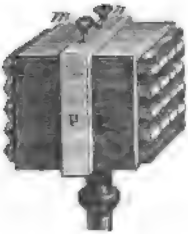
520. What is Saxton's reflecting pyrometer? What of its delicacy? In what service has it been used? What was Borda's mode of measurement? What other system is named?

equal to the one one-hundredth of the expansion between 0° and 100° C., and by the vernier and graduation, these divisions could be read to the one-millionth of the length of the bar. A much more delicate method than that of Borda, has been devised by Silbermann, by which the standard measures sent by France to the U. S., were verified. (Sill. Jour., [2] vol., xx, 413.)

521. **Thermo-electric pile.**—For the detection of exceedingly minute variations of temperature, no instrument is comparable, in delicacy, with Melloni's thermo-electric pile. This instrument consists of a series of small bars of antimony and bismuth, *a* and *b*, fig. 313, soldered together at their alternate ends. Two wires connect the opposite members, *n* and *m*, fig. 313, of this battery, with a galvanometer. The needle of the galvanometer is suspended over a graduated circle, and moves in exact accordance with an electric current produced by the battery. The least difference in temperature between the opposite faces of this battery, produces an electric current, and thus causes the needle of the galvanometer to oscillate. This delicate instrument will be described more minutely hereafter.

313



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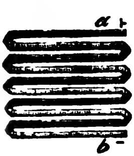

3. *Expansion.*

522. **Expansion of solid bodies.**—When the temperature of bodies is raised, they (with few exceptions) increase in bulk, or expand. Solids expand less for equal increments of heat than either liquids or gases, because of the strong cohesion existing between their particles. Different solids expand unequally, but for the most part, uniformly, in all directions, and return to their original dimensions on cooling.

There are some exceptions to this statement. *Wood* expands and con-

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521. What is said of the thermo-electric pile? Upon what does its delicacy depend? 522. What is expansion? Why do solids expand less than liquids or gases? Do different solids expand alike? Do they return to their original size on cooling? What exceptions are named? Why do lead pipes and linings elongate and wrinkle?

tracts more in the breadth of its fibres than in their length, and when it is considerably heated it contracts permanently. *Clay* also contracts permanently by heating, (517,) and becomes vitrified; new chemical compounds being formed. The particles of *lead* slide over each other during expansion, and do not return again on cooling to their original position. Lead pipes which convey hot water or steam, become permanently elongated from this cause, and the leaden linings of bath tubs and cisterns, which receive hot water, become gathered into ridges.

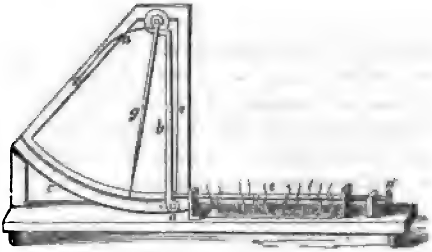
Two kinds of expansion are recognized in solids.—

1st.—Expansion in a single direction, called *linear expansion.*

2d.—Expansion in volume, called *cubical, or total expansion.*

523. **Linear expansion** is shown by the apparatus, fig. 314. One end of a rod of metal, *t*, is in contact with the point of the screw, *o*, and at the other end with a lever, *b*, near its fulcrum *a*. By means of a second lever, *g*, serving as a pointer, any motion of *b* is multiplied in a high ratio. The rod of metal is heated by the flame of alcohol burning below it. As the rod expands, it moves the lever *b*, and thus causes the index, *g*, to move over the graduated arc. The ratio of this motion to that of *b*, being known, the linear expansion of *t* may be calculated. Such an instrument is a pyrometer. All those just described (518, 520) equally illustrate linear expansion.

314



524. **Cubical expansion** may be shown by the apparatus, fig. 315. The ring of metal, *m*, allows the ball of copper, *a*, merely to pass through it at the ordinary temperature. If the ball is heated, it expands in all directions, and will then no longer pass through the ring, but rests upon it, as is shown in the figure. As the ball cools, it gradually returns to its original dimensions, and again passes through the ring as before.

525. **Relation between cubical and linear expansion.**—If a solid is perfectly homogeneous, it will expand uniformly in every

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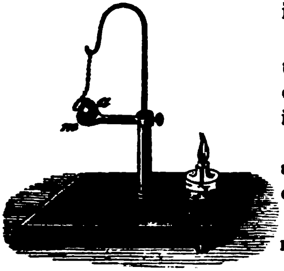
What two kinds of expansion are recognized in solids? 523. How is linear expansion illustrated? Describe fig. 314. What is such an instrument called? 524. How is cubical expansion shown?

direction, by the same elevation of temperature; that is, its length, breadth and depth, will be increased in the same proportion.

315



If a solid was heated to a certain temperature, and increased in length one one-thousandth of its original length, its surface would have increased two one-thousandths of its original area, and its volume, three one-thousandths of its original bulk.

This theoretical view is found to be nearly, but not quite true, in fact.

526. **Expansion of crystals.**—Crystals of the monometric system, (54,) like common salt, fluor spar, &c., expand equally in all directions. In this system all the crystallogenic axes are equal, and at right angles to each other. In crystals of all other systems, the expansion is the same in only two directions, (dimetric system, 55,) or it is different in all three, (57, 58,) depending upon the position of the crystallogenic axes to each other.

The amount of expansion in some crystalline compound bodies, *e. g.*, fluor spar, aragonite, sulphate of barytes, quartz, &c., is found to be greater than in metals, contrary to the generally received opinion. [H. Kopp.]

527. **Uniformity in the expansion of solids.**—Between 32°, and 212° F., the rate of expansion in solids is very uniform, that is, the increase in volume which a solid undergoes is equal for each degree of temperature between these two points. When solids are exposed to temperatures much above 212°, and especially when near the temperature at which they fuse, or melt, their ratio of expansion is found to increase with each increment of temperature, except steel, whose expansion for 1° is less at high temperatures.

The expansion of solids is variously measured. Lavoisier and Laplace placed a bar of the substance under examination in a water bath. One end was fixed, the other free, and touched the end of a lever, turning by any expansion of the bar, and causing a movement in a telescope attached to the lever. This read off the expansions from 32° to 212°, upon a scale placed at a proper distance.

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525. When are linear and cubical expansion equal? What is this ratio? 526. How do crystals of the monometric system expand? How in other systems? What is said of expansion in some compounds compared with metals from which they are derived?

528. **Table of the expansion of solids.**—In the following table, the expansion of the more important substances is given according to the best authorities.

1,000,000 parts at 32° F.	At 212° F. become	Expansion. In length.	Expansion. In bulk.	Authority.
English flint glass,	1,000,811	1 in 1248	1 in 316	Lavoisier & Laplace.
Glass tube, (French,)	1,000,861	1 in 1148	1 in 382	Dulong & Petet.
Platinum, . . .	1,000,884	1 in 1131	1 in 377	
Palladium, . . .	1,001,000	1 in 1000	1 in 333	Wollaston.
Tempered steel, .	1,001,079	1 in 926	1 in 309	Lavoisier & Laplace.
Antimony, . . .	1,001,088	1 in 923	1 in 307	Smeaton.
Iron, ...	1,001,182	1 in 846	1 in 282	Dulong & Petit.
Bismuth, . . .	1,001,392	1 in 718	1 in 239	
Gold, ...	1,001,466	1 in 682	1 in 227	Smeaton.
Copper, . . .	1,001,718	1 in 582	1 in 194	Lavoisier & Laplace.
Brass, ...	1,001,866	1 in 536	1 in 179	
Silver, ...	1,001,909	1 in 524	1 in 175	
Tin, ...	1,001,987	1 in 516	1 in 172	
Lead, ...	1,002,848	1 in 351	1 in 117	
Zinc, ...	1,002,942	1 in 340	1 in 113	Smeaton.

Berthollet has remarked, that in general the most expansible metals are the most fusible, and that the least fusible, (as platinum,) dilate the least. The hardness and ductility of metals does not appear to bear any certain relation to their expansibility.

529. **Table of the increased ratio of expansion with rise of temperature.**—The increase of the ratio of expansion of bodies by rise in temperature, is probably because the distance between the particles augmenting with the heat, their mutual cohesion is more readily overcome.

INCREASE OF MEAN EXPANSION BY HEAT.

	Expansion for each degree F.		
	Between 32° and 212°.	Between 32° and 392°.	Between 32° and 572°.
Glass,	1 in 69660	1 in 65340	1 in 59220
Platinum,	1 in 67860		1 in 65340
Iron,	1 in 50760		1 in 40860
Copper,	1 in 34920		1 in 21060
Mercury,	1 in 9990	1 in 9965	1 in 9518

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527. Within what degrees of temperature is expansion equal? When is it unequal? 528. Explain the table of expansion of solids. 529. What is shown in this table? Why is the ratio of expansion raised with the temperature? Give examples from second table.

INCREASE OF MEAN EXPANSION BY HEAT.

1,000,000 parts at 62° F.	At 212° F.	At 662° F.	At freezing point.
Black lead ware,	1,000,244	1,000,703	
Wedgewood ware,	1,000,735	1,002,995	
Platinum, . .	1,000,735	1,002,995	1,009,926 maximum, but not fused.
Cast iron, . . .	1,000,893	1,003,948	1,016,389
Wrought iron, .	1,000,984	1,004,483	1,018,378 to the fusing point of cast iron.
Copper, . . .	1,001,430	1,006,347	1,024,376
Silver, . . .	1,001,626	1,006,886	1,020,640
Zinc, ...	1,002,480	1,008,527	1,012,621
Lead, ...	1,002,323		1,009,072
Tin, ...	1,001,472		1,037,980

580. **The amount of force exerted by expansion and contraction is enormous, being equal to that which would be required to elongate or compress the material to the same extent by mechanical means.**

A bar of iron one square inch in section, is stretched one ten-thousandth of an inch by a ton weight; the same effect is produced by a variation in temperature of 16° F.

A variation of 80° F. is constantly experienced in these latitudes between the cold of winter and the heat of summer. Between these temperatures, a bar of iron ten inches long would vary in length five one-thousandths of an inch, and would exert a strain, if the ends were securely fastened, equal to fifty tons upon the square inch. It is not therefore remarkable that iron clamps and bars, built into a furnace, frequently destroy the masonry they were intended to strengthen, by the enormous force exerted during their expansion and contraction.

531. **Common phenomena produced by the expansion of solids.**—In every day life may be seen numerous phenomena, caused by the expansion and contraction of substances by variations in temperature.

A stove snaps and crackles when the fire is first lighted, and again when it is extinguished, because of the unequal expansion and contraction of the different parts. The pitch of a piano-forte, or harp, is lowered in a warm room, owing to the expansion of the strings being greater than that of the wooden frame which supports them, and for the reverse reason the pitch is raised, if the room is cooled.

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580. Why is great force exerted by expansion? Illustrate this in the case of iron bars. 531. What common examples illustrate the expansion of solids?

Glass and earthen vessels, with thick walls, are liable to break when hot liquids are suddenly poured into them. The surfaces in contact with the hot liquid, expanding before the other parts are affected, have a tendency to warp, or bend the sides unequally, and the brittle material breaks.

Nails driven into wood often become loose; the expansion and contraction of the nails, through variations of temperature, gradually enlarging the holes. A gate in an iron railing may be easily shut, or opened, in a cold day, but only with difficulty in a warm day, because the gate itself, and the surrounding railings, have become expanded by the heat. Iron bridges are often perceptibly affected by the variations in temperature to which they are subjected; thus the middle of the centre arch of the Southwark, (Eng.) iron bridge, rises an inch in the heat of summer. Each tube of the Britannia tubular bridge, over the straits of Menai, varies in length with the changes of the air from half an inch to three inches in twenty-four hours. This expansion is provided for by the whole being placed on friction rollers.

Bunker Hill Monument, an obelisk of granite two hundred and twenty-one feet high, moves, (as observed by Horsford,) at top, with the sun's rays, so as to describe an irregular ellipse with the sun's motion. This movement commences about seven A. M., of a sunny day, and has its maximum in the afternoon. In a cloudy day, no motion exists, and a shower restores the shaft to its position; showing that the heat which produces the deflection penetrates but a short distance.

Astronomical instruments, placed on elevated buildings, are sometimes sensibly deranged by the expansion of the walls exposed to the sun. Iron and platinum wires may be successfully soldered into glass, because their mutual expansibility differs very little, while silver, gold and copper, similarly treated, crack out as the joint cools, because their expansibility is much greater than that of the glass.

532. **Application of the expansion of solids.**—Many practical applications are made of the expansion and contraction of metals by heat, and mechanical effects are often thus produced, unattainable by other means.

Wheel-wrights and coopers make iron tires and hoops a little smaller than the wheel or barrel for which they are designed. They are applied in a heated state, and quenched; on cooling, they contract, and

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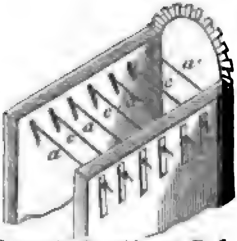
How are musical instruments affected by variations of temperature? Why do glass vessels break if suddenly heated? How do variations of temperature affect iron bridges? Describe the effects of the sun on Bunker Hill Monument. Why are astronomical instruments sometimes used? Why may platinum and not gold wires be soldered into glass tubes? 532. What use do the cooper and wheelwright make of expansion?

bind the parts firmly together. Rail-car wheels are cast with split hubs, to allow play for the unequal contraction of the heavy rims and lighter arms, or the latter would be broken at the hub, or rim, on cooling. The same precaution is requisite in all castings where heavy and light parts are united. Boiler plates are riveted together with red hot rivets, which on cooling, draw the plates together more firmly than any other means could do. When the stopper of a bottle sticks, it may usually be withdrawn by heating the neck of the bottle with a spirit lamp, or with a cloth dipped in warm water. The neck is thus expanded, and the stopper is released.

The walls of an arched gallery in the Museum of arts and trades in Paris, having bulged outwards by the weight of the arch, Molard placed a series of iron bars, *a c*, *a c*, *a c*, *a'* fig. 316, through the walls, secured by nuts on the outside. The bars, *a*, *a*, *a*, *a'*, were first heated by charcoal furnaces, and when they were expanded the nuts were screwed firmly up to the walls, As the bars cooled, they drew up the walls to an extent equal to their contraction. The bars, *c*, *c*, *c*, were in like manner heated, and cooled. By a series of such operations, the walls were gradually brought to an erect position. A similar proceeding was adopted in the Cathedral at Armagh, and in a storehouse in Providence, R. I. The enormous force exerted by expansion has already been shown, (530.)

316



533. **Fire regulators.**—The expansion of solid bodies is often used to regulate the temperature of stoves.

A metallic bar, usually of copper, is placed within, or beside the stove or furnace, and as it becomes heated it expands, and moving a lever, turns a damper, or valve, thus regulating, or arresting the draught, with perfect fidelity and accuracy.

534. **Compensating pendulums.**—The times of the oscillations of a pendulum depend on its length, (161.) A difference of one one-hundredth of an inch in a common pendulum, would cause a clock to vary ten seconds in twenty-four hours ; a difference in temperature of 25° F., produces this effect. Consequently, the pendulum of a clock would move too fast in warm weather, and

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What precaution is required in casting rail-car wheels and other similar pieces ? How are boiler plates joined ? How is a tight stopper loosened ? Describe the case of the Paris Museum. 533. How is expansion used to regulate fire ? 534. How do differences of temperature affect clocks ?

too slow in cold. In ordinary clocks, this defect in the length of the pendulum is remedied, by raising or depressing the ball at the end of the rod by means of a screw. Pendulums in which this defect is remedied by a self-adjusting arrangement, are called *compensating pendulums.* The compensation is effected by the unequal expansion either of mercury and glass, or of different metals. Several of the more common forms of compensating pendulums are described below.

317

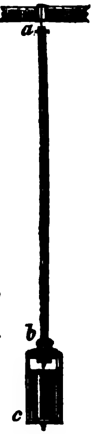
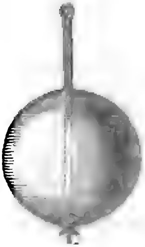


Fig. 317 represents *Graham's compensating pendulum* ; the rod, *a b*, is of glass, and the ordinary weight is replaced by a glass reservoir containing mercury. When the temperature is elevated, the pendulum will be lengthened, and the mercury also expanding, will rise in the glass. The centre of gravity will not alter in its position, for it will be raised by the expansion of the mercury as much as it is lowered by the expansion of the glass rod. As the time of the oscillations does not depend upon the position of the centre of gravity in the pendulum, but on its centre of oscillation, (165,) which do not coincide with it, the compensation is not quite perfect. A perfect compensation is obtained by diminishing or increasing the amount of mercury in the reservoir.

M. Henri Roberts has invented a compensating pendulum, remarkable for its extreme simplicity. The rod of the pendulum, fig. 318, is of platinum, and supports at its lower end a disc of zinc. The centre of gravity of this disc will always be preserved at the same distance from the point of suspension, if the expansion of the platinum rod is equal to that of the zinc disc ; this condition is obtained when the radii of the disc are equal to one-third of the length of the rod.

318



Harrison's gridiron compensating pendulum, is the one most commonly employed ; its action depends on the unequal expansion of two metals. The pendulum, fig. 319, is supported from the middle of a bar, at the extremities of which are placed two iron rods, united at their lower extremity by a cross piece. This also supports two brass rods, united above by a third cross piece, from which are suspended two other iron rods. The cross piece which unites these last bars, again supports two others of brass. Finally, from these last is suspended a third rod of iron, which carries the weight. It is apapparent that the expansion of the brass rods tends to

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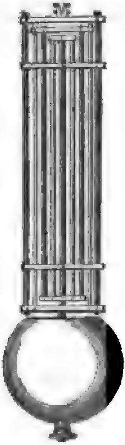
What are compensation pendulums? How is compensation effected? Describe Graham's pendulum. What is Robert's pendulum? Describe Harrison's gridiron pendulum.

raise the weights, while the expansion of the iron rod tends to lower it. The relative lengths of the rods is such, that their expansions compensate each other. The compensation is not, however, quite perfect, but is made so by altering the position of the weight by means of the screw beneath.

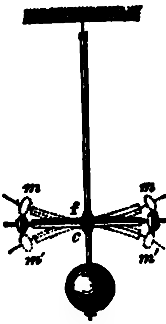
319



A clock maker named *Martin* effected the compensation in pendulums by means of strips of different metals soldered together throughout their length, and fixed transversely upon the pendulum rod, fig. 320. The metals generally employed for the compound strip, are iron and copper; the copper, being the most expansible, is placed below the iron. When the temperature rises, and the centre of oscillation is, by the expansion of the pendulum, removed to a greater distance from the point of suspension, the copper, expanding more than the iron, bends the rod into the curve *m f m*, whereby the metallic balls, *m m*, at the extremities of the rods, are raised, and being brought closer to the point of suspension, compensate for the increased distance of the weight of the pendulum from that point. If the temperature is lowered, the rod bends into the curve, *m′ c m′*, and the balls are lowered. These balls are of such a size, and placed at such a position upon the compound bar, that the centre of oscillation is not displaced by variations in temperature, and thus perfect compensation is produced.

535. Compensating balance wheels of watches and chronometers.—The balance wheels of watches and chronometers, like the pendulums of clocks, vary in dimensions, and consequently in rate of movement, with differences of temperature, and cause corresponding variations in the rate of the time-pieces, which they regulate.

320



This defect is remedied by forming the rim of the wheel of arcs, *a, a, a*, fig. 321, composed of two strips of different metals, the most expansible being placed without; each arc carries, at its extremity, a small weight, *n, n, n*. When the temperature rises, the diameter of the wheel increases, and the arcs, being forced to bend inwards, the weights, *n, n, n*, are thrown nearer the centre of the wheel, and thus produce compensation. The action of unequal expansion in metals, on which compensation balances depends, is well shown by joining firmly

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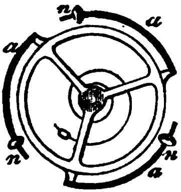
What was Martin's contrivance? How does this produce compensation? 535. How are chronometer balances made compensating? Describe fig. 321.

by rivets two bars, one of iron and one of brass, as in fig 322. When they are heated, the brass, expanding most, will cause the compound bar to bend, as shown in the fig. 323. If they are cooled by ice, the brass, contracting most, will bend the bar of the united metals in an opposite direction.

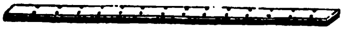
321

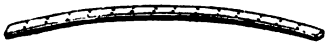


536. **Expansion of liquids.**—All liquids expand by heat more than solids; thus mercury, the least expansible of all liquids, expands more than zinc, the most expansible of all solids.

The rate of expansion in liquids is not uniform, as it is in solids. Especially near their points of solidification and vaporization they are subject to great irregularities. Generally the most volatile liquids are the most expansible.

322





323

537. **The amount of force exerted in the expansion of liquids** is enormous; being equal to the mechanical force required to compress the expanded liquid into its primitive volume.

Thus the expansion of mercury for 10° F., is ·0010085. Its compressibility for a single atmosphere is ·0000053. Therefore the amount of force required to restore the mercury to its original bulk, after heating it 10° F. is equal to 190 atmospheres, (10085 + 53 = 190,) or 2850 pounds pressure to a square inch. Owing to this enormous force exerted during expansion, closed vessels filled with liquid burst when heat is applied.

538. **Apparent and absolute expansion.**—The *apparent* expansion of a liquid is the increase in volume it appears to undergo when contained in a vessel likewise expansible. This is the case with mercury and alcohol in thermometers. The *absolute* expansion is the real increase in volume which a liquid undergoes, as when contained in a vessel not expansible.

The expansion of liquids by heat is determined in a number of ways; sometimes by instruments resembling the thermometer in shape, by ob-

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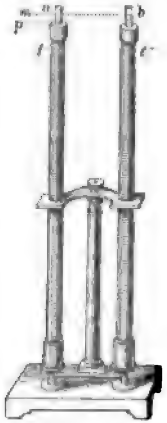
How is this principle illustrated in fig. 322 and 323? 536. What is the comparative expansion of liquids and solids? What irregularity is remarked in the expansion of liquids? What liquids are most expansible? 537. Illustrate the force exerted in the expansion of liquids in the case of mercury.

serving the rise of liquid in the stem; at other times by filling a glass vessel with a known weight of any liquid, and then measuring the volume of liquid expelled by a given increase of temperature. The expansion which the glass vessel undergoes being known, the absolute expansion may then be calculated. The expansion may also be determined by an apparatus, the general idea of which is represented in fig. 324. The principle of its operation is, that the heights of columns of liquid in equilibrium are inversely as their densities, as was explained in 252. A glass tube, *a b*, is bent twice at right angles, having its open ends, *a* and *b*, uppermost. A larger tube surrounds each branch, leaving two cells, closed at bottom, and into which water or other liquids of different temperatures may be poured. The inner tube is filled to the level with the same liquid, alcohol for example, at the ordinary temperature. Hot water is then poured into the outer cell of *t*, and cold water into *t′*. Immediately a rise of the liquid in the *t′* takes place, to a point marked *m b*. The amount of the expansion is determined by measuring the differences in the elevation of the liquid in the two tubes, which elevations are independent of the dimensions of the vessel.

324



The apparent expansion of a liquid is of course always smaller than the absolute expansion. Its co-efficient is equal to the difference between the co-efficients of the expansion of the liquid and the vessel in which it is contained.

539. **Tables of expansion of liquids.**—Liquids expand very unequally for equal increments of heat; the law of their expansion has not been fully determined. Generally the most expansible liquids are those whose boiling points are the lowest. Those whose boiling points are high, have usually a small, but very regular expansibility, especially at temperatures much below their boiling points. The results of Dalton, in the following table, show the apparent expansions of the different substances, no cor-

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538. What is meant by apparent and absolute expansion? How is the expansion of liquids observed? Describe the apparatus, fig. 325. What ratio is there between the columns? What is the co-efficient of expansion in liquids? 539. Illustrate the unequal expansion of liquids from the table.

rections being made for the expansion of the glass vessels in which the experiments were performed.

BETWEEEN 32° AND 212° F.

1,000,000 parts mercury become,	1,018,153	1 in 55.	Regnault.
" " pure water "	1,046,600	1 in 21.3	Dalton.
" " sulphuric acid "	1,058,823	1 in 17.	Dalton.
" " chlohydric " "	1,058,823	1 in 17.	Dalton.
" " oil turpentine "	1,071,428	1 in 14.	Dalton.
" "sulphuric ether"	1,071,428	1 in 14.	Dalton.
" " fixed oils "	1,080,000	1 in 12.5	Dalton.
" " alcohol "	1,111,000	1 in 9.	Dalton.
" " nitric acid "	1,111,000	1 in 9.	Dalton.

It is evident from the above table, that a person buying liquids in winter, will obtain a greater weight of the same material in the same vessel than if he bought in the summer. Thus twenty gallons of alcohol bought in January, will, with the ordinary increase of temperature, become twenty-one in July.

It has been proved that in many liquids of analogous chemical composition, the rate of expansion is nearly uniform at equal distances from their respective boiling points. This fact is amplified in the table immediately below. The figures show the volume of 10,000 parts of different liquids at 72°, and 126° F., below their boiling points. The brackets inclose substances of similar chemical composition.

10,000 parts liquid used.	Volume at 72° below boiling.	Volume at 126° below boiling.
Ether, ...	9384	
Chlorid of ethyl, .	9419	
Acetate of ethyl, .	9424	9053
Acetate of methyl, .	9431	9065
Bromid of methyl,	9438	
Bromid of ethyl, .	9452	9091
Iodid of methyl,	9494	9163
Iodid of ethyl, .	9514	9187
Fousel oil, . . .	9503	9192
Alcohol, ...	9536	9225
Sulphurous ether,	9536	9215

What inference is drawn in the case of alcohol? 540. What is said of the expansion of mercury? What is its expansion below 32° and 312°? What correction for barometric observations are suggested?

540. **Expansion of mercury.**—Mercury is the only liquid whose variations in volume, through a considerable range of temperature, are almost uniform. Between —32°·8 and 212° F., its expansion for equal increments of heat is very nearly uniform, and between 32° and 212° F., it is absolutely so. At temperatures higher than 212°, the expansion is somewhat greater, as is indicated in the following table.

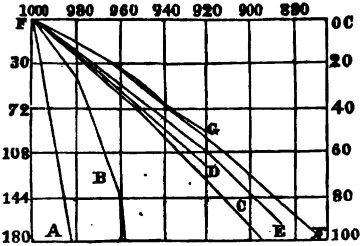
Temperature indicated by air thermometer.	Absolute expansion for each degree F.	Temperature indicated by mercurial thermometer.
32°	0	0
312°	$\frac{1}{9990}$ = 0·0001001001	212° F.
392°	$\frac{1}{9765}$ = 0·0001024065	400°·29 F.
572°	$\frac{1}{9540}$ = 0·0001048020	597°·47 F.

Between 32°, and 212° F., mercury undergoes therefore an increase of bulk, amounting to $\frac{2}{111}$ ($\frac{1}{9990}$ × 180) of its original volume.

As the volume of mercury varies with the pressure, the height of the mercurial column in a barometer, varies not only with changes of the atmospheric pressure, but also with changes in temperature. Before comparing barometric observations, therefore, made at different times, it is necessary to reduce the observed heights of the mercurial column to the height they would have at some standard temperature. The temperature selected in this country is 62° F.; in France, (0°C) 32° F.

541. **Curves of expansion of liquids.**—In fig. 325, the curves show the variations in expansion of some important liquids. In each case, 1000 parts of liquid at a temperature of 212° F., is taken. The horizontal lines (reading from above downwards) show the bulk of the liquid at temperatures below the boiling point. These temperatures are represented in degrees of Fahrenheit's scale on the left hand column, and in centigrade degrees on the right hand. *A*, indicates the contrac-

325



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541. Explain figure 325. 542. What exception does water present in the law of uniform expansion?

tion of mercury; *B*, water; *C*, alcohol; *D*, wood spirits; *E*, formic ether; *F*, terchlorid of silicon; *G*, ordinary ether.

Thus at 108° below the boiling point, (at 104° F.,) 1000 parts water have contracted into 966 parts, alcohol into 931 parts, and formic ether into 918 parts.

542. **Expansion of water.—Point of maximum density.**—Water presents a remarkable exception to the law of uniform expansion of liquids by heat. The temperature of 39°·2 F., is its point of *maximum density*, and if it is either heated above or cooled below this point, it expands.

The maximum density of water is well illustrated by the apparatus, fig. 326. A glass jar, around the central part of which is fitted a metallic vessel, *C*, is provided above and below with two delicate thermometers, *t t′*, entering the sides of the jar horizontally by openings drilled for that purpose. After filling the jar with water, a mixture of ice and salt is placed in *C*. This freezing mixture rapidly cools the water, and the two thermometers continue to indicate the same temperature until the water is cooled to 39°·2 F. After a little time it will be found, that the lower thermometer remains at the temperature of 39°·2, while the upper one indicates a lower temperature, and may finally reach that of 32° F.

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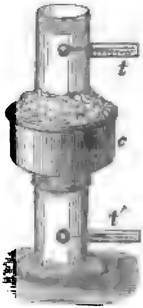

The cause of these phenomena is, that when the water began to be cooled by the freezing mixture, it became more dense and sank, while other and lighter portions rose, and becoming cooled, likewise sank. By such a system of currents, the whole of the water gradually reached the temperature of 39°·2. On cooling below this point, the water expanded, and becoming thus lighter, the colder portion remained at the surface and was further cooled by the freezing mixture, while the water in the lower part of the vessel, not coming in contact with the freezing mixture, and being no longer disturbed by currents, remained at the temperature of 39°·2.

The *maximum density* of water is, therefore, at the temperature of 39°·2 F: since at that point it occupies the least possible space, and is therefore most dense. For a few degrees above and below this point the density of water is nearly the same.

543. **Effects of the unequal expansion of water.**—Under the influence of this law of unequal expansion in water, the cold of

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What is meant by the maximum density of water? How is this law illustrated by figure 326?

our most severe winters produces only a comparatively thin covering of ice upon the lakes and rivers. Water freezes at 32°, but, before that temperature can be reached, expansion sets in at the surface, and the water, although colder, is specifically lighter than the warmer water below, and consequently floats buoyantly upon it. Ice is formed only on the surface, but being a very bad conductor, it cuts off the escape of heat from the water below, and this renders the freezing process a very slow one. In fact, a film of ice may be likened to a blanket, which, although of itself cold, becomes a means of preserving heat by cutting off radiation.

Lake Superior has, uniformly, throughout the year, the temperature of about 40°, a short distance below the surface; and the deep sea soundings show, that the sea, at the bottom of the ocean, even under the Gulf Stream, is below the temperature of maximum density, which, in saline solutions, is lower than in pure water. The temperature of the deep Alpine Lakes is 39°·2 F. at all seasons of the year.

544. **Maximum density of different aqueous solutions.**—The solution of various salts in water has the effect of lowering its point of maximum density. Thus the point of maximum density of sea water is 25°·70. The point of maximum density of solutions lowers more rapidly than their point of congelation, and is proportional to the quantity of salt dissolved.

545. **Expansion of gases.**—Gases and vapors, as might be expected, being under the influence of repulsion, expand for equal increments of heat more than either solids or liquids.

The expansion of air, and of all gases, may be shown by plunging the open end of a bulbed tube into water; a slight elevation of temperature, even the heat of the hand, will expand the air in the bulb, and cause a part of it to escape in bubbles through the water. 507.

546. **Laws of the expansion of gases.**—Gay Lussac established the two following laws for the expansion of gases; they are remarkable for their great simplicity.

1st.—*All gases have the same co-efficient of expansion as air.*

2d.—*This co-efficient is the same, whatever may be the pressure to which the gas is subjected.*

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543. What natural effects are due to this law? Why is the thickness of ice limited? Why is the temperature of Lake Superior and the Alpine Lakes so low? 544. How do dissolved salts affect the maximum density and freezing point of water? 545. What is said of expansion in gases? 546. What are Gay Lussac's laws for the expansion of gases?

These laws are not, however, quite exact in every case, as is shown in the following sections.

547. **Ratio of the expansion of gases by heat.**—It may be stated without sensible error, that air, other gases and all vapors, expand $\frac{1}{491}$ of their volume for each degree of Fahrenheit's thermometer, (343, 344.) From the freezing point to the boiling point of water, they increase, therefore, more than one-third of their bulk; 1000 parts at 32° become 1366 parts at 212° F. The expansion of the different gases is seen in the following table.

Gases.	Co-efficient of expansion for each degree F.	Between 32° and 212° F., 1000 parts become.	
		Regnault.	Magnus.
Hydrogen,	$\frac{1}{491\cdot6}$	1366·13	1365·659
Carbonic oxyd,	$\frac{1}{490\cdot6}$	1366·88	
Atmospheric air,	$\frac{1}{490\cdot7}$	1367·06	1366·508
Nitrogen,	$\frac{1}{490\cdot7}$	1366·82	
Hydrochloric acid,	$\frac{1}{488\cdot9}$	1368·12	
Carbonic acid,	$\frac{1}{485\cdot2}$	1370·99	1369·087
Protoxyd nitrogen,	$\frac{1}{483\cdot9}$	1371·95	
Cyanogen,	$\frac{1}{464\cdot3}$	1387·67	
Sulphurous acid,	$\frac{1}{461\cdot2}$	1390·28	1385·618

The co-efficient of expansion is not absolutely the same for all gases, the expansion being greatest for those which are most readily condensible, whilst for those gases which have resisted all efforts to liquefy them, scarcely any appreciable differences are observed.

The experiments of Dulong and Petit indicate, that the co-efficients of expansion diminishes as the temperature rises. The effect of pressure, however, is directly the opposite of this, for the co-efficient of expansion of all gases, except hydrogen, increases with the pressure; hence the expansion of the different gases becomes more nearly equal as the pressure is feebler.

548. **Formulæ to compute changes of volume in gases.**—In physical researches it is often desirable to ascertain the increase or decrease in volume which a given gas undergoes by measured differences in temperature. This is easily done by the following formulæ.

Let v represent the volume of the gas at 32° F., V its volume at the higher temperature, and T the number of degrees between 32° and the higher temperature. The increase in the volume will therefore be ex-

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547. What is the ratio or co-efficient of expansion in gases? How does it differ? Draw illustrations from the table. How is it affected at high temperatures and pressures? 548. Give the formulæ for calculating the changes of volume in gases, 1st for a lower, 2d for higher temperature.

pressed by $V-v$. And since the increase in volume for 1° F. is (for air) $\frac{1}{491}$, the increase for the higher temperature is,

$$\frac{v}{491} \times T. \quad \text{Therefore,} \quad V-v = \frac{v}{491} \times T.$$

$$\text{Consequently,} \quad V = (1 \times \frac{T}{491}) \times v.$$

If the gas is subjected to a lower temperature, it suffers a diminution in volume, expressed by $v-V$, and if T expresses the number of degrees below 32° to which it is reduced, and $\frac{1}{491}$ its diminution for 1° F., then the diminution for the lower temperature will be

$$\frac{v}{491} \times T. \quad \text{Therefore,} \quad v-V = \frac{v}{491} + T,$$

And therefore,

$$V = 1 - \frac{T}{491} \times v.$$

If the volume of a gas at 32° F., is known, its volume at any other temperature above or below 32° may be calculated by the following

Rule.

Divide the difference between the number of degrees in the temperature, and 32° *by the co-efficient of expansion of the gas, (for air,* 491.) *Add the quotient to* 1, *if the temperature be above* 32°, *and subtract it from* 1, *if it be below* 32°. *Multiply the volume of the gas at* 32° *by the resulting number, and the product will be the volume of the gas at the observed temperature.*

Example: If at 32° the volume of a certain quantity of carbonic acid gas is 187· cubic inches, what is its volume at 79°. 79—32 = 47. 47 ÷ 485·2 = ·09686 ($\frac{1}{485.2}$ co-efficient of expansion of carbonic acid gas.) 1. + ·09686 = 1·09686. 1·09686 × by 187, (the volume at 32°,) = 205·11 c. i., the volume at 79°.

549. **Formulæ expressing general relation between volume, temperature and pressure.**—The volume which a gas occupies depends not only on the temperature, but also upon the pressure to which it is subjected, (343); the pressure of a gas being in direct relation to the volume into which it is compressed.

The volume of a gas at a certain temperature and pressure, being known, it is often desirable to determine its volume at some other temperature and pressure. The relation between the volume, temperature and pressure, is expressed in the following formulæ.

Give the Rule. Also the example. 549. What are the formulæ expressing the general relation between volume, temperature and pressure?

As the volume of a gas at the same temperature is inversely as the pressure, if V and V' be two volumes under the same temperature, and under the pressures P and P'; then,

$$V : V' : : P' : P \quad \text{and } V' = V \times \frac{P}{P'}$$

If T and T' express the number of degrees above and below 32°, at which the temperature stands, (+ being used when above, and — when below,) if a gas be simultaneously subjected to changes of temperature and pressure, the relation between its volume, pressure and temperature, will be expressed by the general formulæ,

$$\frac{V}{V'} = \frac{491 \pm T}{491 \pm T'} + \frac{P'}{P.}$$

550. **Relation between expansibity and compressibility.**—It has been found, generally, that the most expansible liquids are the most compressible.

Solids expand less than liquids, and are likewise less compressible, while liquids have a less expansibility and compressibility than gases. Among solids, the most expansible are generally the most easily compressed.

The expansibility of a substance increases with the temperature, as does also its compressibility.

551. **Effects and applications of the expansion of gases.**—The ventilation of apartments, the heating of buildings by hot air furnaces, the draught in our chimneys, the trade-winds, and the land and sea breezes, are among the effects of the expansion of air by heat. These subjects will be more particularly mentioned hereafter.

552. **Density of gases.**—The density of gases and vapors is compared with atmospheric air as the standard, air being called 1, or 1000. The method for the determination of the density of gases is in principle the same as for the determination of the density of liquids. The determinations are made in a glass globe, fig. 194, (318,) to which an accurately fitted stop-cock is attached. The globe is first weighed, when filled with dry and pure air, and again, after being exhausted of air by means of the air-pump; the difference in the two weights gives the weight of air contained in the flask. The globe is then filled with the perfectly dry gas under examination, and again weighed; the weight found, less the weight of the globe, gives the weight of the gas. The weight of

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550. What are the relations between expansibility and compressibility?
551. What effects and applications of the expansion of gases are named?
552. How is the density of gases determined?

the gas, divided by the weight of the same bulk of air, gives the specific gravity, or density of the gas, as compared with air.

Example: A glass globe held 28·73 grains of atmospheric air, and 43·93 grains of carbonic acid. The specific gravity of the latter is therefore 43·93 ÷ 28·73 = 1·529, or 43·93 : 28 : : 1000 : 1·529.

A number of corrections must be made, in order to obtain the true density of the gas under examination. Thus the barometric height, and the temperature of the air at the time of weighing, must be reduced to the standard barometric height, 30 inches, and the standard temperature, 62° F. Corrections must also be made for the film of hygroscopic moisture, always adhering to the globe, and for the buoyancy of the globe in the air.

Regnault has reduced the number of corrections ordinarily necessary, by counterpoising the globe in which the gas is weighed by a second globe of equal size made of the same glass. Thus the corrections for the film of hygroscopic moisture, and the buoyancy of the globe in the air, may be dispensed with, as they are equal in both cases.

The most important applications of a knowledge of the density of gases have' been made in chemistry: as in demonstrating and elucidating the discovery of Gay Lussac, that the volume of a compound gas is either equal to, or bears a very simple relation to the volumes of its constituent gases. Also, in calculating the atomic weight of numerous elementary substances.

553. **Table of the density of gases.**—In the table below are given the specific gravities of the most important gases, as obtained by distinguished authorities.

SPECIFIC GRAVITY OF GASES AT 32° F. BAROMETER 30 INCHES.

Gases.	Specific gravity by observation,	Specific gravity by calculation.	Observers.
Air, ...	1·000		Dumas & Bousseng'lt
Oxygen, . . .	1·106		" "
Hydrogen, . .	0·0691		
Light carbu. hyd'n,	0·555	0·559	Thomson
Heavy " "	0·978	0·980	Saussure
Chlorine, . .	2·470		G. Lussac & Thenard
Nitrogen, . .	0·972		Dumas & Bousseng'lt
Cyanogen, . .	1·806	1·818	Gay Lussac
Ammonia, . .	0·596	0·591	Biot, Arago
Carbonic oxyd,	0·957		Cruikshank
Carbonic acid,	1·529		Dumas & Bousseng'lt
Sulphurous acid,	2·234		Thenard
Chlorhydric acid,	1·347	1·260	Biot, Arago

Give an example. What corrections need attention? How has Regnault reduced these corrections? What important application has been made in chemistry of the density of gases? 553. State from the table some of the more important densities.

COMMUNICATION OF HEAT.

554. **Communication of heat.**—Heat is communicated in three ways. 1st.—By conduction, (chiefly in solids.) 2d.—By convection, or circulation, in liquids or gases. 3d.—By radiation.

4.—*Conduction.*

555. **Conduction.**—Heat travels in solids slowly, from particle to particle. It implies contact with, or close approach to, a hotter body. The end of a bar of iron thrust into the fire, becomes red-hot, while the other end can yet be handled. Things vary very much in their power to conduct heat, every substance having its own rate of conductibility.

A metallic vessel filled with hot water, is at once as hot as its contents, while an earthen vessel becomes heated slowly. The metal is a good, and the earthenware is a bad conductor. A pipe-stem, or glass tube, held in a spirit lamp, may be heated rod-hot within a short distance of the fingers, where a wire of silver or copper would become at once too hot to hold.

The progress of conducted heat in a solid is easily shown by a metallic rod, to which are stuck by wax several marbles, at equal distances; one end is held in a lamp, when the marbles drop off, one by one, as the heat melts the wax; the nearest the lamp falling first, and so on. If the rod is of copper, they all fall off very soon; but if a rod of lead, or platinum, is used, the heat is conducted much more slowly.

Solids conduct heat better than liquids, and liquids better than gases, which are the poorest conductors of all. The metals, as a class, are good conductors, and their oxyds, as a class, are bad ones. The more atoms of matter then are present in a given body, (*i. e.* the higher its density,) the greater, as a general rule, is its conducting power, and *vice versa.*

556. **Determination of the conductibility of solids.**—The apparatus of Ingenhousz, fig. 327, may be employed to determine the *unequal* conductibility of solids.

This is a small copper box, one side of which is pierced with holes in which are fitted, by means of corks, small cylinders of different substances, of the same size, covered with wax. When the vessel is

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554. How is heat communicated? 555. How does heat move in solids? What is said of conduction? How is difference of conductibility illustrated? What classes of substances are good and what bad conductors? 556. How is the *unequal* conductibility of solids illustrated?

filled with boiling water or hot sand, the wax will be melted from the rods in the order of their conductibility, viz., copper, iron, lead, porcelain, glass, wood. Or small bits of phosphorus may be placed at equal distances upon the rods, and these will be fired in corresponding succession.

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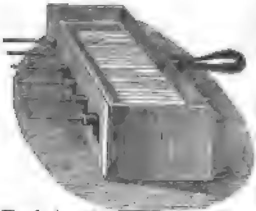

To determine the *relative* conductibility of solids, the apparatus of Despretz may be employed, fig. 328.

It is a series of prismatic bars, *a b*, heated at one end, *a*, by an argand lamp. Each bar has a series of small cavities, *T*, formed in it, at equal distances (1 *c. m.* = (·39 in.) throughout its length, and filled with mercury. In each of these cavities is placed a thermometer, which indicates the progressive propagation of the heat along the bar. Bars of various metals are used. By heating these bars successively over a steady lamp flame, their relative conductibility will be indicated by the times required for them each to attain the same temperature.

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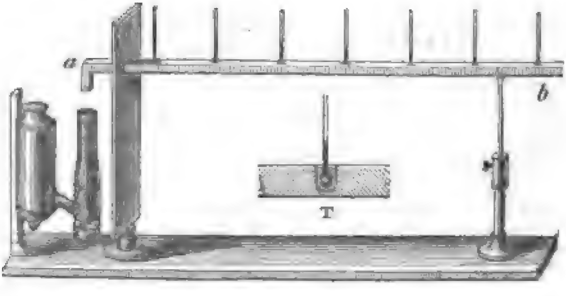

557. **Table of the conductibility of solids.**—The first column of figures in the following table gives the results obtained by Despretz, with the apparatus just described. In the second column are the results obtained by Wiedemann and Franz, with an apparatus in which the temperature of the bar at different parts was determined by means of a thermo-electric pile, thus avoiding the error in Despretz apparatus, occasioned by the al-

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How is their *relative* conductibility determined? Describe the apparatus, fig. 328. 557. Give the conducting power of the more common substances from the table according to different authorities.

teration of the form of the bar by the cavities made for the thermometers, and which partially destroyed the continuity of the metal. The third column gives the results of Becquerel.

	Despretz.	Wiedemann & Franz	Becquerel.
Gold, . .	1000·0	1000·	1000·
Platinum, .	981·0	158·	124·91
Silver, . .	973·0	1880·	1451·37
Copper, .	898·2	1383·	1383·61
Brass, .		444·	
Steel, . .		218·	
Iron, . .	374·3	224·	188·3
Zinc, . .	363·0		375·3
Tin, . .	303·9	273·	212·09
Lead, . .	179·6	160·	128·65
Palladium,		118·	217·08
Bismuth, .		34·	
Marble, .	23·6		
Porcelain,	12·2		
Brick clay,	11·4		

558. **Conductibility of wood.**—De la Rive and Decandolle have shown that wood conducts heat much better in the direction of the fibres than across them. The relative conductibility in these directions is as 5 to 3. Dr. Tyndall has proved that heat is conducted more rapidly in a direction from the external surface towards the centre, than it is in a direction parallel with the ligneous rings. Hard woods conduct heat better than soft, and green woods better than dry.

559. **Conductibility of crystals.**—The conductibility of homogeneous solids, and of crystals belonging to the monometric system, is the same in every direction. But in crystals of other systems, the conductibility varies in different directions, according to the relation of the direction to that of the optic axis of the crystal.

Senarmont, in his experiments, took thin plates of crystals, some cut parallel to the optic axis, and others at right angles to it. In the centre of each plate a small hole was drilled for the reception of a silver wire, which was heated by a lamp; the surfaces of the crystals were covered by a thin coating of colored wax. The conduction of the heat was observed by the melting of the wax, the melted

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558. What is said of the conductibility of wood? 559. How is heat conducted in homogeneous bodies? Mention Senarmont's experiments with crystals.

portion assuming, with crystals of the monometric system, the form of a circle, and in the other systems, ellipses of different forms.

560. **Conductibility of liquids.**—Count Rumford concluded, from his experiments, that liquids were absolutely non-conductors of heat, but later experimenters have determined, that liquids do conduct heat, but only to a very limited degree. That the conductibility of liquids for heat is very slight, is shown by Rumford's apparatus, fig. 329.

The glass funnel is nearly filled with water. A thermometer tube, with large bulb, is so arranged, that the bulb is just below the surface of the water. The stem passes through a tight cork, and contains a few drops of colored liquid at *a*, which will move with any change in bulk of the air contained in the bulb. A little ether poured upon the surface of the water and ignited, does not cause any movement in the column of fluid, (as may be found by pasting a line of paper on the stem at one of the drops of liquid,) which would be the case if any sensible warmth was communicated. The warmth of a finger, touching the bulb, will at once cause the fluid to move by expanding the air within. As the walls of the glass vessel gradually become hot by conduction, the water will slowly rise in temperature. By heating a vessel on the top, therefore, we should never succeed in creating anything more than a superficial elevation of temperature; at a small depth the water would remain cold. The heating of liquids is effected by means of currents, as will be presently explained.

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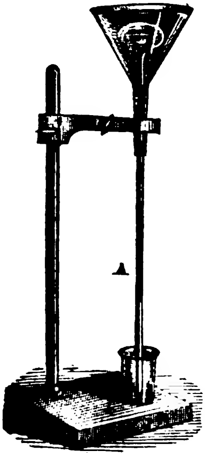

561. **Conductibility of gases.**—Gases are more imperfect conductors of heat than liquids. It is difficult to make accurate experiments upon this subject, from the readiness with which currents are formed, and which thus diffuse the heat, but we know that gases, when confined, are almost non-conductors of heat. Thus, substances which imprison large volumes of air within their pores, as down, wool, feathers, &c., are very poor conductors of heat.

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560. What is said of conduction in liquids? Describe Count Rumford's experiment, fig. 329. How is the heating of liquids accomplished? 561. What is said of conduction in gases?

Air, loaded with moisture, is rendered thereby a much better conductor of heat than dry air, in the proportion of 230 to 80; hence, damp air feels colder to the body than dry air of the same temperature, because it conducts away the heat from the body more rapidly.

562. **Relative conductibility of solids, liquids and gases.**—If we touch a rod of metal heated to 120° F., we shall be burned; water at 150° will not scald, if the hand is kept still, and the heat is gradually raised; while air at 300° has been endured without injury.

The oven-girls of Germany, clad in garments of woolen and thick socks to protect their feet, enter ovens without inconvenience, where all kinds of culinary operations are going on, at a temperature above 300°, although the touch of any metallic article while there would severely burn them.

563. **Examples and illustrations of the non-conductibility of solids**, or more correctly, of the different conductibility of solids, are very obvious to common observation.

The crust of the globe is composed of poor conducting materials, and notwithstanding the intensity of the central fires within, the amount of heat which escapes is so inconsiderable, that it has now no sensible influence on the temperature of the surface. It has been calculated, that the quantity of central heat which reaches the surface in a year would not suffice to melt an envelope of ice surrounding the earth one-quarter of an inch in thickness.

Water-pipes laid at a distance of three or four feet under ground, are not frozen by the winter's cold, because the soil is a poor conductor. Fire-proof safes are boxes of iron, constructed with double or treble walls, the intervening spaces of which are filled with gypsum, (plaster of paris,) burnt alum, or some other non-conducting material. These linings prevent the exterior heat, in case of fire, from passing to the books and papers within. Smelting and other furnaces are lined with fire-bricks, because, being a poor conducting and infusible material, they prevent the waste of heat. Ivory and wooden handles are attached to cooking vessels, and to tea and coffee pots, because, being poor conductors, they prevent the heat from passing to the hand so rapidly as to burn it, which would be

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Why is moist air colder feeling than dry air? 562. Illustrate the relative conductibility of solids, liquids and gases. 563. Give examples of non-conducting solids. What of the earth's crust? Water-pipes? Fire-proof safes? Other examples? Why is water sooner heated in metallic than in earthen vessels?

the case if metal handles were used. Hot dishes are placed upon mats, (of poor conducting material,) as of straw or wicker-work, that the table may not be injured. Water is sooner heated in a metal vessel than in one of glass or porcelain, because the first conducts the heat more rapidly from the fire than the others.

Buildings constructed of wood and brick are cooler in summer and warmer in winter than those of iron, because they are poorer conductors of heat.

The hearth-stone feels colder than the wooden floor, and this than the carpet, owing to the difference in their conducting powers, although all are at the same temperature.

564. **Examples drawn from the animal and vegetable kingdoms.**—The covering of animals not only varies with the climate which the several species inhabit, but also with the season. This covering is not in itself a source of warmth, but prevents the escape of the vital heat from within.

Animals in warm climates are generally naked, or are covered with coarse and thin furs, which in cold countries are fine, close and thick, and are almost perfect non-conducters of heat. The plumage of birds is likewise formed of substances which are poor conductors of heat, containing also a large quantity of air in their interstices. Besides this protection, the birds of cold regions are provided with a more delicate structure beneath the feathers, called down, which intercepts the heat still more perfectly. The fossil elephant of the White River, in Siberia, was covered with three sorts of hair, of different lengths, the shortest being a fine, close wool, next the body, a protection against the arctic colds. The arctic navigator and the Esquimaux, endure the cold of —40°, or —60°, F. with the aid of fur bags and clothes. Animals with warm blood, which live in the water, as the whale and seal, are surrounded with a thick covering of oil and fat, acting in a manner similar to the furs and feathers of land animals.

The bark of trees is much more porous than the wood, and being arranged in plates and fibres around the body of the tree, prevents such a loss of heat as would be injurious to its life.

565. **The conducting power of substances in a pulverized or fibrous state**, is less than that of the same thing in a compact mass, partly because the continuity of the substances is diminished, and also because of the air imprisoned among the particles.

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564. What is said of animal coverings? How are animals clad in warm climates? What is said of the plumage of birds? How is the Siberian elephant clad? How are animals in water protected? What is said of the bark of trees?

Saw-dust in a loose state, is a very poor conductor of heat, much poorer than the wood of which it was formed. Ice-houses are built with double walls, between which dry straw, shavings or saw-dust are placed, keeping the interior cool by excluding the heat. Ice wrapped in flannel, is preserved by excluding the warm air. Refrigerators are generally double-walled boxes, the space between the walls being filled with powdered charcoal, or some other porous non-conducting substance. (See *Ventilation.*) Similar constructed vessels form the ordinary water-coolers.

Snow is made up of crystalline particles, enclosing a large quantity of air among their interstices, which, being a very good non-conductor, prevents the escape of the heat from the earth and limits the penetration of frost, which always reaches a much greater depth in winters without snow, than when snow abounds. On the flanks of mount Ætna, the winter snows often reach near to the border of the fertile regions, and it is the practice of the mountaineers to cover those parts of the snow which they wish to preserve for summer use, with two or three feet thickness of volcanic sand and powdered pumice, everywhere abounding. The snow, thus protected, remains all summer under an almost tropical sun, and is distributed from these natural ice-houses over the whole Island of Sicily. There exists even to this day a heavy bed of ice near the summit of Ætna, covered first by an eruption of ashes and sand several yards thick, and subsequently by a flow of molten lava, many centuries since. This store of ice has been opened and used when the supply below on the mountain fell short. Straw-matting, and other fibrous materials, being poor conductors, are used to envelop tender plants and trees to protect them from severe cold.

566. **Clothing.**—The object of clothing, like the furs and feathers of animals, is to prevent the escape of heat from the body. Fibrous materials, as wool and furs, are best adapted for clothing, because they are themselves very poor conductors of heat, and likewise contain air in their interstices.

Clothing in summer keeps the body cool by excluding the heat, and in winter keeps it warm by preventing its exit.

The order of the conductibility of the different substances used for clothing, is as follows:—linen, silk, cotton, wool, furs. Hence a woolen garment is warmer than one of cotton, or silk, or linen. The sheets of a bed feel colder than the blankets, because they are better conductors of

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565. Why are fibrous and powdered substances warmer than solids? How are ice-houses, refrigerators, &c., constructed? What is said of snow? How is snow preserved on Mt. Ætna? How can ice be preserved by lava? 566. What is the philosophy of clothing? What materials are warmest? What coolest? Why? What will exclude heat?

heat. Fine cloths are warmer than coarse ones because they are poorer conductors of heat. In summer, coarse linen goods are used because they allow the escape of heat from the body more readily than other materials, while a dress of fine, close woolen goods, is a better protection from the cold of winter than anything else excepting furs. A thick dress of similar non-conducting material is sometimes used to exclude heat, as when workmen enter a hot furnace in certain manufacturing processes.

5. *Convection.*

567. **Convection.**—Although liquids and gases are very poor conductors of heat, yet they admit of being rapidly heated by a process of circulation called convection, and which depends upon the free mobility of their particles. The particles of liquids and gases in immediate contact with the source of heat, becoming warm, and also specifically lighter, rise, and, moving away, make room for others; this is continued until all the particles attain the same temperature. Currents are thus produced both in water and air.

568. **Convection in liquids.**—The circulation just mentioned may be rendered visible by heating water in a flask, containing a little bran or amber, (or other substance of about the same density of water,) over a spirit lamp, as shown in fig. 330.

The particles of liquid at the bottom of the vessel, where the heat is applied, becoming heated, rise, and other particles of colder liquid come in below and supply their place. Thus two systems of currents are formed. In the centre of the jar, ascending currents of the hot particles, and descending currents of colder particles flow down the sides; this circulation continues until the whole mass has attained the same temperature. If the vessel is allowed to cool, the currents flow in the opposite direction.

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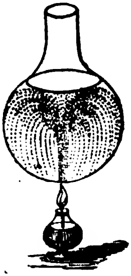

Anything that checks this free circulation, and occasions viscidity, impedes the heating of the liquid, and likewise prevents its rapid cooling.

Starch and gum, during boiling, require to be constantly stirred for the purpose of presenting fresh surfaces to the action

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567. What is convection? In what forms of matter does it act to carry heat? 568. How is convection illustrated in liquids? What obstructs rapid heating of liquids?

of the heat, and preventing portions from adhering to the hot bottom, and thus being burned.

569. **Currents in the ocean.**—In consequence of the unequal heat to which the waters of the ocean in different parts are subjected, currents of great constancy and regularity are formed. Under the tropics, the waters become highly heated and flow off on either side toward the poles, while other colder currents flow from the poles towards the equator. These currents are modified in their direction by the form and distribution of land and water on the surface of the earth, and the rotation of the earth upon its axis.

One of these currents, (called for that reason the Gulf Stream,) is directed into the Gulf of Mexico, around the western end of Cuba, and sweeping through it, passes by the narrow channel between Florida and the Bahama Islands. It has a temperature 8° or 10° F., higher than that of the surrounding ocean. This current passes northward, parallel to the coast of the United States, gradually widening and becoming less marked, and finally is directed toward the frozen ocean and British Islands. It carries away the excess of heat from the Antilles, and warm regions near the equator, beyond the western Atlantic, ameliorating the climate of the British Islands and all north-western Europe.

The researches of the U. S. Coast Survey have greatly extended our knowledge of this remarkable river of the ocean, (or rather union of many rivers of warm water,) first brought to the notice of the scientific world by the illustrious Franklin in 1770.

6.—*Radiation.*

570. **Radiation of heat.**—Hot bodies radiate heat equally in all directions. Radiant heat proceeds in straight lines, diverging in every direction from the points where it emanates. These diverging lines are called *thermal rays*, or *heat rays*. It is generally by radiation, that bodies become heated at a distance from the source of heat.

Standing before a fire, or in the sun's light, we feel the genial influence of the heat radiated from these sources. A candle, or gas light, gives off its heat as it does its light, in all directions. A thermometer

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569. How are currents excited in the ocean? Describe the Gulf Stream. Where does it originate and where end? What is its temperature? What has extended our knowledge of it? Who first called attention to it? 570. What is radiant heat? How do bodies radiate heat? How does heat move? What are these lines called? Give the illustrations. 571. How is radiant heat affected by media?

placed at equal distances from the flame, in any direction, indicates the same temperature.

571. **Radiant heat is not generally absorbed by the media through which it passes**, and is not sensibly affected by any motion of the media, as of winds in air.

The rays of heat from the sun do not warm the air through which they pass, but proceed to the earth where they are absorbed. The air receives its warmth by conduction and convection, from the surface of the earth thus heated by the sun.

We receive warmth from the fire upon our persons, although the air remains cold, and may be continually renewed.

The conduction of heat through bodies, is probably a radiation from particle to particle.

572. **Intensity of radiant heat.**—The intensity of radiant heat is according to the following laws:

1st.—*It is proportional to the temperature of the source.*

2d.—*It is inversely as the square of the distance from the source.*

3d.—*It is as much greater as the rays are emitted in a direction more nearly perpendicular to the radiating surface.*

1st. If a thermometer be exposed at the same distance from different sources of heat, having, for example, the temperatures of 100°, 150°, and 200°, the amount of radiant heat will be directly as these numbers.

2d. Thus the heating effect of a body at a distance of two feet is only one-fourth, at three feet, one-ninth, and at four feet, one-sixteenth of what it is at one foot. This law may be exemplified by supposing two globes, one of one foot diameter, the other of two feet diameter, having a body equally heated in both. The larger globe exposes four times as much surface as the smaller one; consequently each square inch of the larger one will receive only one-fourth as much heat as each square inch of the smaller one, while the distance to this surface is only twice as great.

3d. This law may be demonstrated by the apparatus, fig. 331. In the focus of the mirror, a thermoscope, *f*, is placed. *A A*, *B B*, are screens pierced with equal openings. The vessel, *a c*, is filled with hot water. The position of the index of the thermoscope will be the same, whether *a c*, is perpendicular, or more or less inclined. And, as in the latter case, there is a greater surface exposed, and consequently a greater num-

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How is the air warmed? How may radiation explain conduction? 572. Give the first law of radiant heat. Give the second law. Give the third law. What illustration is there of law first? What of law second? Describe the apparatus illustrating law third, fig. 331.

ber of heat-rays pass through the screen, yet as the same effect is produced, the oblique rays must be less intense than the perpendicular rays, the intensity diminishing with their obliquity.

573. **Law of cooling by radiation.**—Newton supposed, that the rapidity of cooling of a body was proportional to the difference between its temperature and that of the surrounding medium. This law is correct only for those bodies differing in temperature not more than 15°or 20° C, (59° to 68° F.)

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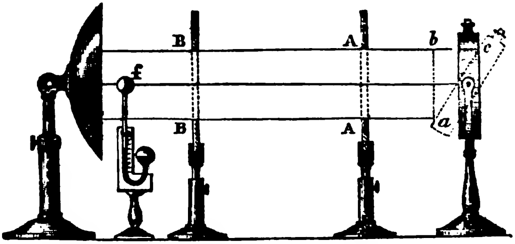

Dulong and Petit made elaborate investigations upon this subject, and determined that where the heated body was placed in vacuo at temperatures ascending according to the terms of an arithmetical progression, the rapidity of cooling increased according to the terms of a geometrical progression: diminished, however, by a constant quantity, this constant being the heat radiated back upon the cooling body from the walls of the confining vessel. If the temperature of the vessel, and that of the heated body, were both raised according to the terms of an arithmetical progression, so that the difference between the two was always constant, the rate of cooling increased according to the terms of an arithmetical progression.

Radiation is found to take place more freely in vacuo than in air.

574. **Universal radiation of heat.**—Heat is radiated from all bodies, at all times, whether their temperature be the same or different from surrounding bodies; for it is the tendency of heat to place itself in equilibrium.

In an apartment where all the articles are of the same temperature, each receives as much heat as it radiates, and consequently their tempe-

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573. What did Newton suppose respecting cooling? What is the fact? What have Dulong and Petit demonstrated? What is said of radiation in vacuo? 574. What is said of the universal radiation of heat? How is this illustrated?

rature remains stationary. Where some bodies are warmer than others, the warmer radiate more than they receive, until finally all attain the same temperature. Hence all bodies, however cold, will warm bodies colder than themselves; thus frozen mercury, placed in a cavity of ice, will be melted by the heat radiated from the ice.

575. **Apparent radiation of cold** takes place when two parabolic mirrors are placed opposite to each other, having a delicate thermometer in the focus of one, and a mass of ice suspended in that of the other. The temperature of the thermometer will be seen to fall, apparently by the radiation of cold from the ice. The true explanation is, that the thermometer is warmer than the ice, and radiating more heat than it receives, thus loses heat, and the temperature falls. If the thermometer had been at a lower temperature than the ice, the phenomenon would have been reversed, and the ice would have been cooled. The following remarkable instance of the apparent focalization of cold is explained in a similar manner.

If a parabolic mirror is placed with its axis pointing towards the sun, the heat-rays will be reflected to the focus of the mirror. But if the mirror be turned so as to face the clear blue sky, its focus becomes a focus of cold, and a delicate thermometer placed at that point will sink, in clear weather, some degrees in the day time, and as much as 17° F. at night. This phenomenon is thus accounted for; the thermometer is constantly radiating heat in all directions; the mirror, being a paraboloid, reflects to its focus only those rays that come in a direction parallel to its axis. In that direction no rays come, for there is no source to reflect them, consequently the temperature of the thermometer falls. If a cloud passes over the axis of the mirror, the thermometer instantly rises to its usual height.

576. **Reflection of heat.—Conjugate mirrors.**—Radiant heat, like light, is reflected at the same angle at which it falls upon any reflecting surface. This law in respect to light will be fully illustrated in the chapter on that subject.

If a piece of bright tin plate is held in such a position as to reflect the light of a clear fire into the face, the sensation of heat will be felt the moment the light is seen.

Conjugate mirrors.—The reflection of heat may be shown in a still more striking manner by the apparatus called the conjugate mirrors, fig.

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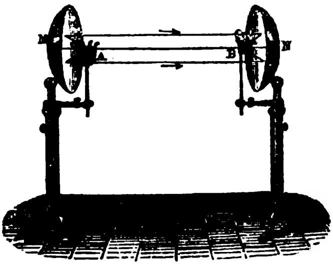
575. How is the apparent radiation of cold explained? What example of this apparent radiation is afforded by the clear sky? How is this phenomenon explained? 576. How is heat reflected? Illustrate this.

332, consisting of two similar parabolic mirrors, arranged exactly opposite to each other at a distance of ten or twelve feet. In the focus of one mirror is placed a heated body, as a mass of red-hot iron, and in the other a portion of an inflammable substance, as gun-powder or phosphorus. Certain of the heat-rays pass directly from *A* to *B*, the greater part, however, reach *B*, by being twice reflected. The mirror, *M*, reflects the rays emitted from *A*, in a direction parallel to its own axis; these are received by the second mirror, *M*, and by reflection are conveyed to the focus, *B*, igniting the gun-powder or phosphorus placed at that point.

332



The reflection of heat in vacuo, takes place according to the same laws as in air.

577. **Determination of reflective power.**—Different bodies possess very different powers of reflection. This is well illustrated by the apparatus, fig. 333, designed by Leslie.

The source of heat is a cubical tin canister, *M*, filled with boiling water. A plate, *a*, of the substance whose reflective power is to be determined, is placed between the mirror and its focus. The rays of heat emitted from *M*, which are directed upon the mirror, *N*, are reflected upon the plate, *a*, and from this, upon the bulb of the thermoscope, placed at the point where the rays are brought to a focus. The temperature indicated by the thermoscope is found to vary with the nature of the plates.

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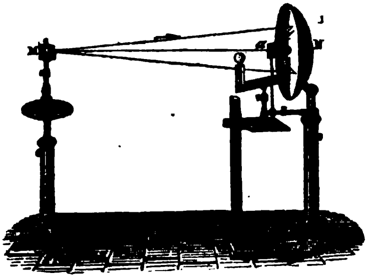

The causes which modify the reflective power of bodies will be given (with examples) hereafter.

578. **Absorptive power.**—Different bodies possess very different powers of absorbing the heat thrown upon them. The absorptive power of a body is always in the inverse ratio of its re-

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Explain the conjugate mirrors and their action, fig. 332. How is heat reflected in vacuo? 577. How is the different reflective power of bodies illustrated? Describe Leslie's apparatus, fig. 333. 578. How is absorption related to reflection of heat?

flective power; that is, the best reflectors are the worst absorbents, and *vice versa.* The sum of the reflected and absorbed heat, however, is not quite equal to the whole amount of the heat thrown upon the body, because a small portion is reflected irregularly in all directions.

The absorptive power of bodies may be determined by a modification of the apparatus, fig. 333. At the focus of the mirror, *N*, is placed the bulb of a thermoscope, which is successively covered with different substances, as with lampblack, Indian ink, gum lac, metallic leaf, &c., Leslie has been the principal experimenter in this department of heat. The numbers in the following table differ somewhat from those obtained by Leslie. They are the results of the elaborate experiments of M. M. de la Provostaye and Desains, and confirmed by Melloni.

Names.	Radiating and absorbing power.	Reflective power.
Smoke blackened surface,	100	0
Carbonate of lead,	100	0
Writing paper,	98	2
Glass,	90	10
China ink,	85	15
Gum lac,	72	28
Silver foil on glass,	27	73
Cast iron, polished,	25	75
Mercury, (nearly,)	23	77
Wrought iron, polished,	23	77
Zinc polished,	19	81
Steel,	17	83
Platinum, thick coat, imp'ly polished,	24	76
" on copper,	17	83
" leaves,	17	83
Tin,	14	80
Metallic mirrors a little tarnished,	17	83
" " nearly polished,	14	86
Brass, cast, imperfectly polished,	11	89
" hammered, imp. "	9	91
" " highly polished,	7	93
" cast, " "	7	93
Copper, coated on iron,	7	93
" varnished,	14	86
" hammered, or cast,	7	93
Gold plating,	5	95
" deposited on polished steel,	3	97
Silver, hammered, and well polished,	3	97
" cast, and well polished,	3	97

Why is the sum of these quantities never equal? How is absorptive power determined? Who was the chief authority on this subject? Who have more lately corrected Leslie's results? Give examples selected from the table. How are the different absorptive power of bodies illustrated?

All black and dull surfaces absorb heat very rapidly when exposed to its action, and part with it again slowly by secondary radiation. The different powers of absorption, possessed by the different colors, may be illustrated by repeating Franklin's experiment. Pieces of the same kind of cloth, of different colors, were placed upon the snow; the black cloth absorbed the most heat, so that after a time it sunk into the melted snow beneath it, while the white cloth produced but little effect; the other colored cloths produced intermediate effects. Ranged according to their absorbent powers, we have, 1. Black, (warmest of all,); 2. Violet; 3. Indigo; 4. Blue; 5. Green; 6. Red; 7. Yellow; and 8. White, (coldest of all.)

579. **Emissive power.**—The emissive power of bodies is the property they possess of giving out heat; it varies very greatly with different substances. The emissive and absorbent power of bodies are always equal to each other.

Leslie employed in his experiments the apparatus, fig. 333. A bulb of a thermoscope was placed in the focus of the mirror, the other bulb being protected from the radiant heat by a screen. The cubical vessel containing boiling water, has its lateral faces covered with different substances, which are successively turned toward the mirror.

The table below gives the results as obtained by Leslie. Lampblack possessing the greatest emissive power, is called 100.

Lampblack,	100	Indian ink,	88	Polished lead,	19
Water, (by calc'n,)	100	Ice,	85	Mercury	20
Writing paper,	98	Minimum,	80	Polished iron,	15
Sealing wax,	95	Plumbago	75	" silver, tin,	
Crown glass,	90	Tarn'd lead,	45	" copper, gold,	12

M. M. de la Provostaye and Desain, and also Melloni, in more recent investigations upon the metals, have obtained results differing from those of Leslie.

Lampblack being	100	Rough silver, (deposited on copper,)	5·36
Pure rolled silver,	3·00	Burnished silver " chem.	2·25
" burnished silver,	2·50	Burnished platinum,	9.50
Rolled platinum,	10·80	Sheet copper,	4·90
Gold in leaf,	4·28		

580. **Causes which modify the emissive, absorbent and reflective powers of bodies.**—The reflective power being inversely

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Who devised the mode of experiment? Name the colors in the order given. 579. What is emissive power? What apparatus did Leslie experiment with on this subject? What are his results? How have these been modified and by whom?

proportional to the others, any causes which increase them diminishes it, and the contrary.

Not only do different bodies possess the powers of reflection, absorption and emission in different degrees, but the physical condition of the material effects them in an important manner. So also the obliquity of the incident rays, the source of heat, and the thickness of the superficial layer, exercise great influence.

The absorbent and emissive powers of metallic plates are diminished if they are hammered or polished. The opposite effect is produced if the plates are scratched or roughened. This is doubtless owing to the change in density which the superficial layers of the plates undergo by these operations. For the same reason, the reflective power of a substance is generally increased by polishing or hammering, and diminished by roughening or scratching it; which latter also causes a portion of the heat to be irregularly reflected. That this is the true explanation is probable from the fact, that if such materials as ivory or coal are taken, whose density will not be changed by roughening or polishing, the reflective and absorbent powers remain the same. The thickness of the superficial layer has an influence on the reflective power of bodies. Leslie covered a mirror with successive coatings of varnish; the reflection diminished as the number of layers increased, until their thickness amounted to twenty-five thousandths of a mille metre, (0·025 m. m.,) when it remained constant. While a vessel covered with layers of varnish or jelly had its emissive power increased with the number of layers, until they reached sixteen, (with a thickness of 0·034 m. m.,) when it remained constant, even upon the addition of other layers. The absorbent power of substances varies with the nature of the source of heat. Thus a substance covered with white lead, absorbs all the thermal rays from copper, heated to 212° F.; 56 of those from incandescent platinum; 58 of those from an oil lamp. Lampblack is the only substance which absorbs all the thermal rays, whatever be the source of heat. This subject will be more particularly considered hereafter.

The absorptive power varies with the inclination of the incident rays, the smaller the angle of incidence the greater is the absorption.

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580. What causes modify the emissive, absorbent and reflective powers of bodies? Illustrate this. Why should hammering or polishing affect these powers? What effect has the thickness of superficial layers on reflection and what on emissive power? What varies the absorbtive power of substances? How is it affected by obliquity of rays? How is it in glass and metal surfaces?

This is one of the reasons why the sun heats the earth more in summer and less in winter.

The reflective power of glass increases with the angle of incidence, but with metallic surfaces the same proportion is reflected at all incidences up to 70°, beyond this the proportion of reflected heat diminishes.

581. **Applications of the powers of reflection, absorption and radiation** are often made in the economical use of heat. We shall refer only to the more familiar examples.

Meat-roasters and Dutch-ovens are constructed of bright tin, to direct the heat from the fire upon the article cooking.

Hoar frost remains longer in the presence of the morning sun upon light colored objects than upon the dark soil, because the latter absorbs much of the heat, while the former, reflecting it, remain too cold to thaw the frost. Water is slowly heated in bright metallic vessels, as in a silver cup or a clean bright kettle, because they are poor absorbents, but if the sides and bottom of the vessels become covered with soot, the water is heated quickly.

To keep a liquid warm it should be contained in a vessel composed of a poor radiating material. Hence if tea and coffee pots, &c., are made of polished metal, they retain the heat much longer than those which have a dull surface or are composed of earthenware.

Stoves of polished sheet-iron radiate less heat, but keep hot longer than those made of cast iron with a rough and dull surface.

Pipes conveying steam should be kept bright or thoroughly covered with felt or cloth until they reach the apartments to be warmed, and there their surfaces should be blackened in order to favor the process of radiation.

582. **Mirrors and reflectors** are spherical or parabolic surfaces of glass or metal highly polished, serving to concentrate at one point luminous or thermal rays. Parabolic mirrors have been before named (576.) A spherical mirror is a section of a sphere whose concave surface is brilliantly polished. In order to apply to a spherical mirror the laws of reflection from plane surfaces, it is supposed to be made up of an infinite number of immeasurably small, flat faces—a polygon, with an infinite number of faces. The rays reflected from these surfaces, come together at one point, called the focus, propagating intense heat.

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581. What use is made in culinary operations of the laws of reflection? Why is hoar frost not soonest melted on light colored objects? Why is water slowly heated in a bright, and rapidly in a black kettle? How are liquids kept warm? How should steam-pipes be arranged for conveying and emitting heat? 582. What are mirrors or reflectors? How do they concentrate heat?

Kircher and Anthemius constructed compound mirrors of wonderful power, but the most remarkable was that constructed by Buffon. His mirror was composed of one hundred plane glass mirrors, silvered on the back, and hinged, so that they formed a spherical surface. This produced a concave mirror whose focal distance might be varied at pleasure. With this apparatus Buffon melted sliver at one hundred, lead at one hundred and forty feet, and kindled wood at two hundred feet. This renders the story of Archimedes' and Procus credible.

7.—*Transmission of radiant heat.*

583. **Transmission of radiant heat.**—Light passes through all transparent bodies from whatever source it may come. The rays of heat from the sun also, like the rays of light from the same luminary, pass through transparent substances with little change or loss. Radiant heat, however, from terrestrial sources, whether luminous or not, is in a great measure arrested by many transparent substances as well as by those which are opaque.

The glass of our windows remains cold, while the heat of the sun, passing through it, warms the room. But a plate of glass held before the fire will stop nearly all the heat, although the light will be undiminished.

Melloni terms those bodies which transmit heat *diathermanous*, or *diathermic*, (from the Greek, *dia*, through, and *thermaino*, to heat,); those bodies which do not allow this transmission of heat are termed *athermanous*, or *adiathermic*, (from *alpha*, privative, and *thermaino*.)

It appears that many substances are eminently diathermanous, which are almost opaque to light; smoky quartz for example.

M. Prevost of Geneva, and M. De la Roche in France, in 1811 and 1812, discovered many of the phenomena of diathermanous bodies, but it is from the beautiful researches of Melloni, in 1832—1848, that our knowledge upon this subject has been chiefly derived. Melloni, called by De la Rive "the Newton of heat," died of cholera at Naples, in Aug. 1854.

584. **Melloni's apparatus.**—The apparatus used by Melloni in his researches upon the transmission of heat, is represented in all its essential details in fig. 334.

How is the surface of a spherical mirror conceived of? What effects will such mirrors produce? What is said of Buffon's mirror? What did it do? 583. What is said of the transmission of light and heat by media? How is this with respect to terrestrial heat? How does a pane of glass illustrate this? Define Melloni's terms, diathermic, &c. Are opacity to light and heat associate qualities?

At one end of the graduated metallic bar, *L L*, is placed the thermo-multiplier, *m*, fig. 334, and in connection with it, by fine wires, *A B*, the anastatic galvanometer, *D*. Upon the stand, *a*, is placed the source of heat; in this case a Locatelli lamp. *F* is a double screen to prevent the radiation of the heat from the source, and is lowered at the moment of observation. *E* is a perforated screen which allows only a certain quantity of rays to pass through it and to fall upon *C*, which represents the substance whose diathermacy is to be determined.

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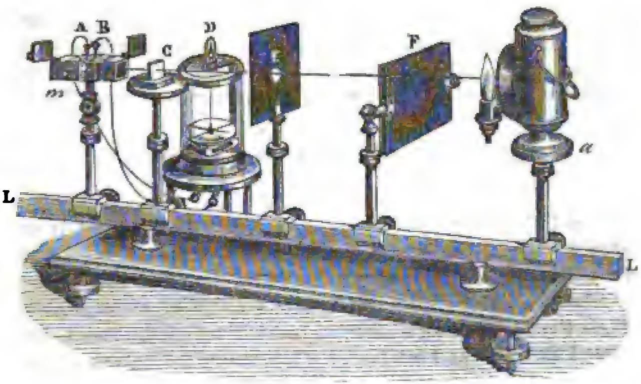

In experimenting, the source of heat is placed at such a distance, that when *F* is removed, the heat directed upon *m*, will cause the needle of the galvanometer to move through 30°. The screen, F, is then raised, and the plate, *C*, to be experimented upon, is placed upon the stand. When the needle of the galvanometer has returned to 0°, (its normal position,) the screen, *F*, is removed. The proportion of heat transmitted through the plate, *C*, is then indicated by the arc of vibration of the needle, over the dial plate of *D*. The construction of the galvanic multiplier and thermoscope will be more particularly described in the chapter on thermo-electricity.

585. **Influence of the substance of the screens.**—In experimenting with liquids, they were placed in glass cells. The stratum of liquid was 9·21 m. m. (·362 in.) in thickness. The source of heat used was an argand oil lamp.

Who have contributed to our knowledge in this department, and when? 584. Describe Melloni's apparatus, fig. 334. How is the apparatus used? What indicates the heat? 585. What was the mode of experiment on liquids, and what source of heat was used?

DIATHERMACY OF DIFFERENT LIQUIDS.

Of 100 incident rays.	trans-mitted		trans-mitted
Bisulphid of carbon, (colorless,)	63·	Ether,	21·
Bichlorid of sulph., (red brown,)	62·	Sulphuric acid, (colorless,)	17·
Terchlorid of phosphorus,	62·	Sulphuric acid, (brown,)	17·
Essence of turpentine,	31·	Nitric acid,	14·
Colza oil, (yellow,)	30·	Alcohol,	15·
Olive oil, (greenish,)	30·	Distilled water,	11·

The independence of transparency and diathermacy is well seen in the above table; the bisulphid of carbon transmitted three times as many heat-rays as ether, four times as many as alcohol, and more than five times as many as water, although these liquids are equally transparent and colorless.

The quantity of heat transmitted through different solids of the same thickness is very variable, as is shown in the following table.

586. **Influence of the nature of the source.**—The nature of the source of heat exercises a great influence on the diathermic power of bodies. Melloni, in his experiments, used four different sources of heat; they are indicated in the table below.

DIATHERMACY OF DIFFERENT SOLIDS.

Each plate was 2·62 m. m. (1 in.) thick.	Naked flame.	Ignited platinum.	Copper 750° F.	Copper 212° F.
Rock salt, (limpid,)	92·3	92·3	92·3	92·3
Silician sulphur, (yellow,)	74·	77·	60·	54·
Fluor spar, (limpid,)	72·	69·	42·	33·
Rock salt, (cloudy,)	65·	65·	65·	65·
Beryl, (greenish yellow,)	46·	38·	24·	20·
Iceland spar, (limpid,)	39·	28·	6·	0·
Plate glass,	39·	24·	6·	0·
Quartz, (limpid.)	38·	28·	6·	3·
Quartz, (smoky,)	37·	28·	6·	3·
White topaz,	33·	24·	4·	0·
Tourmaline, (dark green,)	18·	16·	3·	0·
Citric Acid,	11·	2·	0·	0·
Alum,	9·	2·	0·	0·
Sugar candy, (limpid,)	8·	1·	0·	0·

Illustrate the relations of transparency and diathermacy in fluids by the table. 586. What influence has the nature of the source on transmission? What sources were used? Illustrate the relation of transparency and diathermacy in solids, from the table.

Those solids which are transparent to light do not necessarily allow the passage of heat, and *vice versa*. Thus sulphate of copper transmits the blue rays of light, but entirely arrests the rays of heat. Again, black mica, smoked rock salt, and opaque black glass, transmit a considerable portion of the heat-rays, but prevent the passage of light.

From the above table it appears, that rock salt is the only substance that permits an equal amount of heat from all sources to pass through it. Melloni experimented with plates of this substance of a thickness varying from one-twelfth of an inch to two or three inches, and in all cases 92·3 of 100 rays incident upon them were transmitted. The loss of 7·7 per cent. being due to a uniform quantity which is reflected at the two surfaces of the plate. Rock salt is, therefore, to heat, what clear glass is to light, and well deserves the name which Melloni gave it, of *the glass of heat*.

587. **Other causes which modify the diathermic power of bodies** are the degree of polish, the thickness and number of the screens, and also the nature of the screens through which the heat has been previously transmitted.

The quantity of heat which a diathermic body transmits, increases with the degree of polish of its surface. The diathermic power of a body diminishes with its thickness, although according to a less rapid rate. Thus with four plates whose thickness was as the numbers 1, 2, 3, 4; of 1000 rays, the quantity absorbed by each was, respectively, 619, 577, 558, 549. So that beyond a certain thickness of the body, the quantity of heat it can transmit remains nearly constant. Rock salt is the only exception to this law; it always allows the same quantity of heat to pass through it, at least for thicknesses between 2, and 40 m. m., (·0787 and 1·575 in.)

The increase of the number of screens produces a similar effect to an increase of thickness. If many plates of the same kind are placed together, they absorb more heat than one plate having the combined thickness of several, owing to the numerous surfaces.

The thermal rays which have passed through one or more diathermic bodies, are so modified, that they pass with more facility through other diathermic bodies than direct rays do. Thus the heat from an argand lamp, where the flame is surrounded with a glass chimney,

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What thickness of plates was used? What solid admits the passage of most rays of heat from all sources? What has Melloni called it? 587. What other circumstances modify diathermacy? How does thickness of screens affect it? How if the number of screens is increased? How do rays from a naked and glass-covered lamp-flame pass?

differs much in its transmissibility from the heat of a Locatelli lamp, where the flame is free and open. Thus in making use of an argand lamp surrounded with a glass chimney, and a Locatelli lamp which is not thus protected, Melloni obtained the following results.

Of 100 rays.	Argand lamp.	Locatelli lamp.
Rock salt transmitted,	92	92
Iceland spar "	62	39
Quartz (limpid) blackened, trans.,	57	34
Sulphate of lime, "	20	19
Alum, "	12	7

588. **Thermochrosy**, or *heat-coloration*, (*thermos*, heat, and *chroma*, color.)—As Newton has shown that a pencil of white light is composed of different colored rays, which are unequally absorbed and transmitted by different media, and which may be combined together or isolated, so Melloni argues from his results, that there are different species of calorific rays emitted simultaneously in variable proportions by the different sources of heat, and possessing the property of being transmitted more or less easily through screens of various substances.

If a pencil of solar light falls successively upon two plates of colored glass, one red and the other bluish-green, it will be wholly absorbed, the second plate absorbing all the rays transmitted by the first. This is precisely analogous to what may happen with a thermal pencil, its entire absorption being caused by passing it through two media successively, each of which absorbs the rays transmitted by the other. Viewed in this manner, it may be said that rock salt is colorless as respects heat, while alum, ice and sugar-candy, are almost black. It is a fact of common observation, that snow melts more quickly under trees and bushes than in those spots which receive the direct rays of the sun. This is proved by Melloni to be owing to the fact, that the rays emitted by the heated branches are of a different nature from the direct rays of the sun, and more easily absorbed by snow than the latter.

589. **Applications of the diathermacy of bodies.**—The air is undoubtedly very diathermic, or else the upper layers would be heated by the solar rays passing through them, while the reverse we know to be true.

Illustrate this from the table. 588. What is thermochrosy? Illustrate it by the analogy of white light. How do red and blue-green glass affect solar light? What analogy is there in the effect of screens on heat-rays? Why does snow melt sooner beneath trees than in open spaces? 589. Why is the air judged to be diathermous? Name illustrations from the arts and physical experiments.

In certain processes of the arts, workmen protect their faces by a glass mask, which allows the passage of the light but arrests the heat.

Plants are often reared under close glass vessels, (Wardean cases,) the solar rays alone penetrating into the interior.

In certain physical experiments, where heat is to be avoided, the light is first passed through a solution or plate of alum, whereby the *heat is arrested.* On the contrary, if the heat is directed upon rock salt covered with lampblack, the *light is arrested* but the heat passes through undiminished.

590. **Probable independence of light and heat.**—Certain of Melloni's experiments would seem to prove the independence of light and heat.

By transmitting a solar beam first through a glass vessel filled with water, which stopped the less refrangible rays, and then through a peculiar green glass tinged with copper, which stopped the more refrangible rays, a greenish beam was obtained, which, although concentrated by lenses, produced no evidence of heat upon the most delicate thermoscope.

A similar separation of heat and light is effected in nature in the light reflected by the moon. Dr. Wollaston received the beam of the full moon, concentrated by a powerful lens of Sir Jos. Banks', in his eye, without feeling the least heat. M. Melloni obtained only an extremely feeble indication of heat by concentrating the rays of the moon by a lens over three feet in diameter, and directing the brilliant focus of light upon the face of a very sensitive thermo-multiplier.

591. **Close analogy between heat and light.**—The more carefully the phenomena of light and heat are studied, the more perfect does the parallel between radiant heat and light become. Besides the analogies already mentioned, radiant heat, like light, may be polarized, (see light,) and Knoblauch has recently obtained distinct evidence of the diffraction and interference of the rays of heat.

592. **Refraction of heat.**—If a ray of heat or light passes from one medium to another of different density, the ray is bent more or less out of its path, and on emerging into the original medium, resumes again its original direction.

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590. What experiments indicate the independence of heat and light? Is the moon's light accompanied by heat? Mention the evidence. 591. What is said of the close analogy between heat and light? How is this illustrated? 592. What is refraction?

Thus if a ray of heat, *S*, falls obliquely upon a diathermic body, in fig. 335, its direction is altered as it enters the object, as from *A* to *T*, and it continues in its new direction in a straight line until it leaves the body, when it again resumes a direction, *T V*, parallel to its first course.

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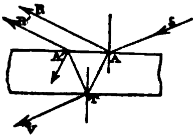

593. **Lens.**—The burning glass or double convex lens, has the form shown in fig. 336. The axis of the lens is the straight line *M F*, passing through the centres of the faces. The focus, *F*, is the point where the refracted rays converge after being transmitted through the lens. It is only with a lens of rock salt, that the rays of all our sources of heat can be condensed, for a lens of glass affects only the solar rays, and becomes itself heated by artificial heat.

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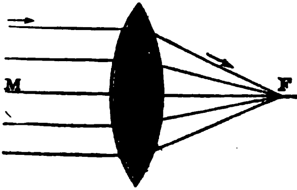

A lens of *ice* was made in England in 1763, having a diameter of 3 metres, (118·112 in.,) at whose focus gun-powder, paper, and other combustibles were inflamed. Burning glasses have generally more power than mirrors of equal diameter. Both produce their more intense effects on high mountains after a fall of snow, for then the air is free from moisture, and the solar rays lose less of their intensity in passing through it.

CALORIMETRY.

8.—*Specific heat.*

594. **Calorimetry**, (*calor*, heat, and *metron*, measure,) is the measurement of the quantities of heat which different bodies absorb or emit during a known change in temperature, or when they change their state. Water, having the highest specific heat, is selected as the standard of comparison in these experiments.

The thermal unit, in this country and in England, is the quantity of heat which is necessary to raise a pound of pure water

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593. How does a lens affect heat-rays? Explain the burning glass from fig. 335. What is said of ice for a lens? When are the best effects of burning glass seen? Why? 594. What is calorimetry? What is the standard of comparison? What is the thermal unit here? What in Europe?

from 32° to 33° F. In France, and in Europe generally, the thermal unit is the quantity of heat necessary for raising one kilogramme (2·20486 lbs.) of water from 0° to 1° C (= 32° to 33°·8 F.)

595. **Specific heat.**—Different bodies have different capacities for heat; that is, equal weights of different bodies require unequal quantities of heat to raise their temperature a certain number of degrees. If equal weights of water and mercury at the same temperature be placed over the same source of heat, it will be found, that the mercury becomes heated much more quickly than the water. That when the water is heated 10° the mercury will have become heated 330°; the capacity of water for heat is, therefore, 33 times as great as that of mercury. Each substance in this regard has its own capacity for heat. This relation is called *caloric capacity*, or more commonly, *specific heat*.

Three methods have been devised for determining the specific heat of bodies: these are, 1st, the method of mixture; 2d, the melting of ice; 3d, by cooling.

596. **Method of mixture.**—This method is exceedingly simple in theory, and approximate results may thus be easily obtained.

If a pint of water at 150° be mixed quickly with a pint at 50° F., the two measures of water will have a temperature of 100°, or the arithmetical mean of the two temperatures before mixture. If, however, a measure of mercury at 50° be mingled with an equal measure of water at 150°, the temperature of the mixture will be 118°. The mercury has gained 48° while the water has lost 32°. Hence it is inferred, that the same quantity of heat can raise the temperature of mercury through twice as many degrees as that of water, and that the specific heat of water is to that of mercury as 1 : 0·47 when compared by measure.

If, however, equal weights of these bodies be taken, the resulting temperature is then still more in contrast. A pound of mercury at 40°, mixed with the same quantity of water at 156°, produces a mixture whose temperature is 152·3. The water loses 3°·7, while the mercury gains 112°·3, and therefore, taking

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595. What is specific heat? Illustrate this from water and mercury. What is their relative capacity for heat? How in regard to other bodies? What methods are given for determining specific heat? 596. Describe the method of mixtures. Is the comparison made by weight or measure? Illustrate it from the case of mercury and water. How is it applied to solids?

the specific heat of water as 1, that of the mercury will be 0·033, since,

$$3°·7 : 1· : : 112°·3 : x = (0·033.)$$

In determining the specific heat of solids by this method, a weighed mass of each substance is heated to the proper degree, and is then plunged into a measure of water of known temperature and weight. The elevation of temperature produced in each case is carefully noted.

597. **Method of fusion of ice.**—This method is founded on the quantity of ice melted by different bodies in cooling, through the same number of degrees.

The most simple form of experiment consists in placing the heated body, *W*, whose specific heat is to be determined, in a cavity made in a compact block of ice, fig. 337, and then closing the cavity by a plate, *b*, of the same material. During the cooling, a definite weight of the ice is melted, and the specific heat is determined from the weight of the fusion-water produced as compared with the temperature and weight of the substance under trial. Several sources of error attach to this method of experiment. Lavoisier and Laplace contrived the apparatus, fig. 338, called a calorimeter. It consists of three vessels made of sheet tin or copper. In the interior vessel, *c*, pierced with holes and closed by a double cover, is placed the substance whose specific heat is to be determined. This is entirely surrounded by ice contained in the second vessel, *b*, and also on the cover. In order to cut off the heat of the surrounding air, the exterior vessel *a*, is also filled with ice. The water from the ice melted in this outer vessel, passes off by the stop-cock, *r*. The body in the interior vessel, cooling, melts the ice surrounding it, and the water from it flows off through the stop-cock, *s*, and is weighed.

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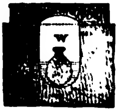

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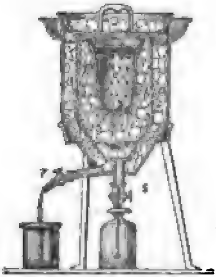

The specific heat of different substances is determined in this apparatus by the comparative weights of the water produced during the experiments; in which a certain weight of each

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597. What is the 2d method? Describe fig. 337. Describe the calorimeter of Lavoisier, fig. 338, and its use. How is specific heat measured by this. How in case of a liquid? What objections exist?

body cools from an agreed temperature, *e. g.*, (212° F.,) to 32°, the constant temperature of the vessel *C.*

The specific heat of a liquid is determined by placing it in a vessel, as of glass, whose specific heat is known. The amount of ice melted by the liquid, is the whole quantity of water produced, minus that which would be melted by the glass alone.

This method, though excellent in principle, is subject to many inaccuracies, which render the results incorrect.

598. **Method of cooling.**—This method is founded on the different rates of cooling of equal masses of different substances; those having the greatest specific heat cooling most slowly.

Equal volumes of the bodies, whose specific heat is to be determined, are placed successively in a very thin metallic vessel, in the centre of which is a delicate thermometer. Solids must be reduced to powder in order to render their conductibility as equal as possible. The vessel containing the body under examination, is surrounded by a second vessel, maintained at a constant temperature, or better, in a vessel from which the air is exhausted. The times required to cool the bodies a certain number of degrees, as from 212° to 60°, compared with the time required to cool water through the same thermometric interval, represents approximately the specific heat of the bodies in question.

599. **Specific heat of gases.**—The specific heat of gases is either the quantity of heat which is necessary to raise the gases 1° in temperature, compared either with an equal *weight of water*, or with an equal *volume of air.* The specific heat of gases is generally determined when under a constant pressure, but sometimes when confined within a given volume.

600. **Tables of the specific heats of solids, liquids and gases.**—In the following tables, the first column gives the specific heat of different elementary solids and liquids as determined by Regnault.

The second column gives the atomic weights, (on the hydrogen scale,) and the numbers in the third column are the product of the multiplication of those in the first, by those in the second column. The law deduced from this relation is given in 604.

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598. What is the third method? On what is it founded? How is it applied? How to solids? What precautions are used? In what terms are the results obtained? 599. What is the specific heat of gases? How is it generally determined? What is the mode in comparison with air?

SOLIDS.

Water — 100.

Names.	Specific heats. C.	Atomic weights. p.	Product, C x p.
Aluminum, . . .	0·2143	13·7	2·94
Sulphur, ...	0·2026	16·	3·24
Iron, ...	0·1138	28·	3·19
Cobalt, ...	0·1070	29·5	3·16
Nickel, ...	0·1086	29·6	3·21
Copper, ...	0·0952	31·7	3·02
Zinc, ...	0·0956	32·6	3·12
Selenium, . . .	0·0762	40·	3·04
Tin, ...	0.0562	59·	3·31
Platinum, . . .	0·0324	98·7	3·20
Lead, ...	0·0314	103·7	3·26
Phosphorus, . .	0·1887	31·	5·85
Arsenic, ...	0·0814	75·	6·10
Silver, ...	0·0570	108·	6·16
Iodine, ...	0·0541	127·	6·87
Antimony, . . .	0·0508	120·3	6·11
Gold, ...	0·0324	197·	6·38
Bismuth, ...	0·0308	208·	6·41

LIQUIDS.

Mercury, (liquid,)	0·03331	100	3·33
Mercury, (solid,)	0·03241	100	3·24
Bromine, (liquid,)	0·11094	80	
Bromine, (solid, 28°C.	0·08432	80	6·74

The following table of the specific heat of gases contains the results as obtained by Delaroche and Bêrard.

Simple gases or mixtures.	For the same volume air being 1.	For the same weight air being 1·	For the same weight water being 1.
Air, ...	1·000	1·00	0·2669
Oxygen, . . .	0·9765	0·8838	0·2361
Hydrogen, . .	0·9033	12·3401	0·2936
Nitrogen, . .	1·000	1·0318	0·2753
Compound gases.			
Carbonic acid,	1·2583	0·8280	0·2210
Protox. nitrogen,	1·3503	0·8878	0·2369
Olefiant gas,	1·5530	1·5763	0·4207
Oxyd of carbon,	1·0340	1·0805	0·2884

600. What is shown in the tables here given? Give the results for iron, and mercury, and hydrogen.

601. **Mechanical compression, affecting specific heat.**—Any change affecting the relative distance between the particles of a body, varies its specific heat.

602. **Decrease of temperature in the atmosphere from elevation.**—The specific heat of æriform bodies, like that of solids and liquids, increases by condensation and diminishes by rarefaction. The continued diminution in temperature as we ascend in the atmosphere, is due chiefly to this cause.

The average diminution in temperature in ascending from the sea level is 1° F. for every 300 feet. Supposing the average temperature of the air at the level of the sea, near the equator, to be 80°, and toward the poles 0°, the figures in the second and third column of the following table will express approximately the temperature at different elevations.

Decrease of temperature in the atmosphere from elevation.

Altitude in feet.	Equatorial temperature.	Arctic temperature.
0·	80°	0°
5,000·	64°·4	— 18°·5
10,000·	48°·4	— 37°·8
15,000·	31°·4	— 58°·8
20,000·	12°·8	— 82°·1
25,000·	— 7°·6	—109°·1
30,000·	—30°·7	—140°·3

603. **Specific heat of the same body in a liquid or solid state.** A body in the liquid state has a greater specific heat than when it is in the solid form, as might naturally be concluded from the fact, that the addition of heat is necessary to convert the solid into a liquid.

Thus ice has a specific heat of 0·505, water being 1000, sulphur (solid,) 0·2026—fluid, 0·2340; phosphorus, between 45° and —6°, 0·1887, at 212°, 0·2045, &c.

The high specific heat of water moderates very greatly the rapidity of natural transitions from heat to cold and from cold to heat, owing to the large quantity of heat emitted or absorbed by the ocean in accommodating itself to variations in external temperature.

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601. How does mechanical compression affect specific heat? 602. How do condensation and the reverse affect the specific heat of gases? What is the average diminution of temperature in ascending in the air? Illustrate these differences from the table. 603. How do the specific heats of the same substance as solids and liquids compare? Illustrate this from the table. How does the specific heat of water affect climate?

604. **Relation between the specific heat and atomic weight of elements.**—Dulong and Petit, from their researches upon the elements, were led to conclude, that the ultimate atoms of all elements possessed the same capacity for heat, and they accordingly announced the law, that,

The specific heat of elementary substances is in inverse ratio to their atomic weights.

This law appears to be true for most of the elements, as will be seen by examining the table of atomic weights and specific heats in 600. It will be noticed, that the one increases in almost the exact proportion in which the other diminishes, and that by multiplying them together, a very nearly constant product is obtained. Some elements, as those given in the lower part of the table, gives a product (C×p) double of the others. So that equivalent weights of these would contain twice as much heat as equivalent weights of those first given.

605. **The relation between the specific heat and atomic weight of compounds** is expressed by Regnault in the following law.

In all compound bodies containing the same number of atoms and of similar chemical constitution, the specific heats are in inverse ratio to their atomic weights.

9.—*Liquefaction and solidification.*

606. **Latent heat.**—During the conversion of a solid into a liquid, or of a liquid into a gas or vapor, a certain quantity of heat disappears which is not perceptible for the time to the thermometer or to the senses. This is called latent heat.

607. **Disappearance of heat during liquefaction.**—That a large quantity of heat disappears during the liquefaction of a solid is apparent from the following experiments.

Let a pound of ice and a pound of water, each at the temperature of 32°, be exposed to the same source of heat in precisely similar vessels. It will be found, at the moment when all the ice is melted, that the water into which it is converted has still the temperature of 32°; while the temperature of the other pound

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604. What did Dulong and Petit infer respecting atomic weights and specific heats of elements? What is their law? How is this law illustrated in the table in 600? What numbers produce a constant product? 605. What is the relation between the specific heat and atomic weights of compounds? Give Regnault's law. What exceptions are these laws subject to? 606. What is latent heat? What changes give evidence of it? 607. What experiment illustrates the disappearance of heat during liquefaction?

of water has risen from 32° to 174°. As both have received the same amount of heat, it follows, that the 142° which have disappeared, have been used in converting the ice into water, and have become latent.

If a pound of water at 212° be mixed with a pound of powdered ice at 32°, when the ice is melted the two pounds will have the temperature of only 52°; the ice gains only 19° while the water loses 161°. Here again 142° have disappeared or have become latent.

608. **Liquefaction and congelation are always gradual**, owing to the absorption or evolution of heat during these processes. If this was not so, water at 32° would immediately become ice, upon losing the smallest additional portion of its heat, and on the other hand, ice would suddenly pass from the solid to the liquid state by the smallest addition of heat.

This fact, coupled with the law of irregular expansion of water, will explain why ice never acquires any very great thickness. The high specific heat of water acts to moderate the natural changes of temperatures.

609. **Table of latent heat.**—The most accurate experiments upon this subject have been made by M. Person; he concludes that,—

The latent heat of fusion is obtained by multiplying the difference between the specific heat of the substance in its liquid and solid form, by the quantity obtained by adding the number 256 (*an experimental constant furnished by researches upon the latent heat of water*) *to the melting point of the substance in question.*

TABLE OF LATENT HEAT.

	°F.	Water =1		°F	Water =1
Water,	142·65	1·000	Cadmium,	25·44	0·171
Nitrate silver,	113·34	0·704	Bismuth,	22·75	0·159
" potash,	85·26	0·598	Sulphur,	16·85	0·118
Zinc,	50·63	0·355	Lead,	9·65	0·067
Silver,	37·92	0·265	Phosphorus,	9·05	0·063
Tin,	25·65	0·179	Mercury,	5·11	0·035

Give the particulars. How much heat disappears in this experiment? How is the same fact otherwise illustrated? 608. Why are liquefaction and congelation gradual? What if this was not so? Explain this more particularly. Why is the air chilled when snow and ice melt? 609. What is Person's law regarding latent heat? Explain the table.

The number in the second columns may be considered as the number of pounds of water that could be raised 1° F. by the heat emitted during the congelation of one pound of each of the substances included in the table.

610. **Freezing mixtures.**—Solids cannot pass into the liquid state without absorbing and rendering latent, a certain amount of heat. If the heat necessary for the liquefaction is not supplied from some external source, the body liquefying will absorb its own sensible heat. A knowledge of this fact enables us at pleasure, in the hottest seasons and climates, to produce extreme degrees of cold.

The so-called *freezing-mixtures* are compounds of two or more substances, one of which is a solid. These, when mixed together, enter into combination and liquefy. The operation should be so conducted, that no heat can be absorbed from external sources, and hence as the substances liquefy, a depression of temperature results, proportional to the heat rendered latent.

The most convenient freezing mixture is salt 1 part, and ice or snow 2 parts, universally used in the freezing of ices and creams. With this freezing mixture, a temperature of —4° or —5° below zero can be maintained for many hours. A solution of equal parts of nitre and sal-ammoniac will reduce the temperature from 50° to 10° F. Very well constructed ice-cream freezers are now commonly sold in the shops, in which an adroit use has been made of the laws of radiant heat, to facilitate the rapidity of this operation.

Thilorier, with a mixture of solid carbonic acid and sulphuric acid, or sulphuric ether, obtained a temperature 120° below zero. More lately, Mitchell obtained by the same means a temperature of 130° and 146° F. At the former temperature, alcohol (den. 798) had the consistency of oil, and at the latter temperature resembled melting wax.

In the liquefaction of metallic alloys, a similar depression is observed. When an alloy composed of 207 parts lead, 118 tin and 284 bismuth; is dissolved in 1617 parts mercury, the temperature will sink from 63° to 14° F.

In producing extreme degrees of cold, the substance to be operated upon is first cooled to a certain degree by a less powerful freezing mixture, before the more energetic one is used; the full effect of the latter is thus obtained.

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610. On what fact do freezing mixtures rest? What are freezing mixtures? What is the most convenient mixture? What others are noticed in the table and what temperatures do they produce? What of metallic alloys? How low a temperature has been obtained by solid carbonic acid and sulphuric ether? How are freezing mixtures most economically applied? Give examples from the table.

TABLE OF FREEZING MIXTURES.

Substances.	Parts by Weight.	Cooling.
Sulphate of soda,	8	from + 50° to 0°
Hydrochloric acid,	5	
Snow or ice,	2	“ x “ —5°
Common salt,	1	
Sulphate of soda,	3	“ + 50° “ —3°
Dilute nitric acid,	2	
Sulphate of soda,	6	“ + 50° “ —14°
Nitrate of ammonia,	5	
Dilute nitric acid,	4	
Snow or ice,	3	“ + 20° “ —14°
Chlorid of calcium,	4	

611. **Laws of fusion.**—Expansion (the first effect of heat) has a limit, at which solids become liquids. The powers of cohesion are then subordinate to those of repulsion, and fusion results.

Fusion takes place in accordance with the following laws.

1st.—*All solids enter into fusion at a certain temperature, invariable for the same substance.*

2d.—*Whatever may be the intensity of the source of heat when the fusion commences, the temperature remains constant until the whole mass is fused.*

The freezing points of some of the more important substances are given in the following table.

TABLE OF FUSING POINTS.

	°F.	Authority.		°F.	Authority
Mercury,	—39°	Regnault.	Bismuth,	518°	Person
Oil of vitriol,	—30°		Lead,	633·2°	
Bromine,	— 4°		Zinc,	773°	Daniell
Ice,	32°		Antimony,	963·6°	Plattner
Phosphorus,	111°·5	Scrötter.	Silver,	1873°	Daniell
Potas'm, (ab't,)	131°·		Copper,	2004.8	Plattner
Yellow wax,	143°·6	Person.	Gold,	2016	Daniell
Sodium, (ab't,)	190°·		Cast iron,	2786	
Iodine,	224°·6			above	
Sulphur,	239°·	Person	Wro'ght iron,	3280	
Tin,	451°·		Platinum,	4591·2	Plattner

612. **Peculiarities in the fusion of certain solids.**—Certain solids soften before becoming liquefied, while others never become entirely fluid.

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611. What limits has expansion? What are the laws of fusion? Explain this table.

Thus many organic substances, as tallow, wax and butter, soften at temperatures below those at which they fuse. This is undoubtedly owing to the fact, that they are composed of several separate substances which melt at various temperatures.

Those metals, like iron and platinum, capable of welding, soften before they fuse. Pieces of such metals heated until they soften, may be joined together by hammering, or severe pressure. Some substances, again, never attain perfect fluidity, as is the case with glass and certain metals, which always remain more or less viscid. The fusion of sulphur also presents striking peculiarities. (See *Chemistry.*)

613. **Refractory bodies.**—Substances difficult of fusion are called refractory bodies.

Among the most refractory bodies are silica, the earths lime, baryta, alumina, &c. Their fusion may be effected by the ox-hydrogen blow-pipe, or by the use of the galvanic battery. By these means also the fusion of platinum is effected, which resists the heat of a powerful blast furnace, although a thin wire of this metal can be melted by the mouth blow-pipe.

Carbon is the most refractory of all bodies. Its fusion has not yet been perfectly effected; although, by means of the galvanic battery, Professor Silliman obtained, (in 1822,) unequivocal evidences of the volatility and partial fusion of this substance: and more lately these results were verified by M. Despretz, with a carbon battery of 600 cups; boron and silicon also yielding to the same power.

614. **Solution—Saturation.**—When a solid immersed in a liquid gradually disappears, the process is termed solution. Thus sugar and salt dissolve in water, camphor in alcohol, &c. Solution is the result of an adhesion existing between the particles of a liquid and those of a solid. A liquid is said to be saturated when at a given temperature it has dissolved as much as possible of a solid.

The causes which diminish cohesion among the particles of a solid, generally facilitate solution. Thus a pulverized body dissolves quicker than the same quantity in large masses. Heat also facilitates solution by diminishing the cohesive force and producing currents.

615. **Laws of solidification.**—The passage of a body from the

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612. What peculiarities do some solids present in fusing? Give examples. What is welding? Mention the peculiarities in glass and sulphur. 613. What are refractory bodies? Enumerate some of them. How are they fused? What is said of the fusion of carbon? 614. What is solution?

liquid to the solid state, always occurs in accordance with the following laws.

1st.—*The solidification of a body takes place at a certain fixed temperature, which is also that of its fusion.*

2d.—*The temperature of a body remains constant from the commencement to the end of its solidification.*

616. **Elevation of heat during solidification.**—When liquids return to the solid state, the heat which has been absorbed during their liquefaction, and rendered latent, is given out.

If the solidification takes place suddenly, the heat evolved is often very apparent. Examples of this fact have already been given. (86, 88.) In the sudden solidification of water, the freezing of a part gives out heat enough to raise the temperature of the whole from 22° or 23° to 32°, or through 8° or 10°. Thus we arrive at the seeming paradox, that freezing is a warming process; and owing to the absorption of heat during liquefaction, it is equally true, that melting is a cooling process. Hence, in part, the cooling influence of an iceberg or of a large body of snow on a distant mountain.

Potassium and sodium when pressed together evolve heat enough to fuse the mass into a pasty alloy, with bright globules on its surface. With mercury, they form a solid amalgam, and in the act of uniting with it, they evolve sufficient heat to set fire to the naptha which is adhering to the surface, and often to explode the mass violently.

617. **Change of volume during solidification, and its effects.**—Mercury and most metals contract while solidifying; hence the freezing of a mercurial thermometer does not burst its reservoir. Water expands during freezing to the amount of one-seventh of its bulk: hence ice floats on the surface of water, and close vessels even of iron are burst, if frozen when full of water.

This fact is familiar to house-keepers, who prevent the bursting of their water-casks during winter by a stick of wood placed in the cask, about which the bulge from expansion takes place. Aqueduct service-pipes are often saved from the same accident in cold weather by allowing the water to flow uninterruptedly, thus preventing the formation of ice crystals, both by motion and the supply of warmer water.

A brass globe filled with water burst at 32° in the experiments of the Florentine academicians, who estimated the force exerted as equal to 28,000 pounds. A bomb-shell filled with water and tightly closed

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615. What are the laws of solidification? 616. What change of temperature is noticed in solidification? Give illustrative examples. Why is freezing a warming, and melting a cooling process?

by an iron plug, when exposed to severe cold in Montreal, discharged the plug to a distance of 400 feet, and a cylinder of ice eight inches in length protruded from the hole.—All metals which, like water, assumes the rhombohedral form on solidification, produce sharp casts, (87.) Such are cast-iron, antimony, tin, zinc, and bismuth. All alloys capable of producing sharp casts must contain such a metal. Type metal, (3 lead and 1 antimony,) brass, (2 copper and 1 zinc,) and bell-metal, (7 copper and 3 tin,) are familiar examples. Copper, lead, gold, silver, and indeed most metals, except those above enumerated, crystallize in the monometric system (54) and hence occupy less space as solids than as fluids, producing imperfect casts. Hence coins are stamped, and gold, silver and copper utensils and ornamental wares are wrought by the hammer, or stamped, to secure sharpness and beauty.

618. **Freezing of water.**—Water ordinarily freezes at 32°, but it has already been stated, (86 and 88,) that under certain circumstances it may be cooled near to 22° and remain liquid. If, however, water is turbid or contains carbonic acid, it always freezes at 32°.

Certain experiments made in France indicate, that the temperature to which water may be exposed without freezing, falls in proportion as it is exposed in tubes of smaller diameter. This remarkable circumstance seems to throw light upon the fact, that plants whose capillaries are full of juices resist frost in a manner so noticeable as many of them do. Nevertheless, in very severe weather, the boles of large trees are burst open by frost.

Water, containing salts in solution, freezes at a lower temperature than pure water. Thus sea water freezes at 27°. The ice formed from salt water and from impure or turbid water is comparatively fresh and pure, since it is the water which freezes and not the foreign bodies it contains. Frozen ink and other colored fluids, precipitate the coloring matter, and are spoiled as colors until by boiling the precipitate is again diffused. Like-

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What is said of potassium and sodium? 617. What is said of change of volume during solidification? How is it with mercury? What is said of water? What is the increase of bulk in ice? What effects follow the freezing of water? What metals expand on becoming solid? What is type metal? What metals diminish in solidifying? Why do gold and silver make bad casts? 618. What is said of the point at which water freezes? What is said of tubes of small diameter? What important inference is drawn from this? How do solids and foreign substances affect the freezing of water? What is said of ice from sea water? What of ink, &c. How are rocks affected by freezing? How is the value of building-stones determined?

wise cider and other weak alcoholic liquors exposed to moderate cold, congeal, but only the watery portion, and the alcoholic part may thus be obtained in a more condensed state.

Some absorbent rocks are pulverized and gradually covered by a thick bed of soil, by the effects of freezing water in breaking down their solid mass. The value of building-stones in our climate depends much upon the resistance they offer to the action of frost. In hot climates the effect is not seen, and the crags and summits of mountains are there generally more sharp. Experiments to determine the resistance of rocks to frost are made by saturating cubes of the material with water and repeatedly freezing them. But the same result is more conveniently obtained by using a solution of sulphate of soda. This salt, crystallizing on exposure to the air, effects the same results.

10.—*Vaporization and Condensation.*

619. **Vaporization.**—Liquids become vapors upon receiving a certain quantity of heat. Thus water at 212° is rapidly converted into steam, which at or above that temperature remains as an invisible gas. This change of state presents some of the most interesting and important phenomena of physics.

Evaporation occurs only at the surface of liquids, quietly, as in the insensible changes of water to vapor in an open vessel. *Boiling* or *ebullition*, is the rapid formation of vapor throughout the whole mass of liquid, producing more or less agitation. *Sublimation* is the change of solids to vapors without the intermediate liquid condition. Arsenic, iodine and camphor, are examples of solids which may be so changed.

The remarkable disappearance of nearly one thousand degrees of heat when water is turned into steam, (and correspondingly for other liquids,) will be discussed under Latent heat.

620. **Formation of vapors in a vacuum.**—Evaporation takes place slowly in the open air, owing chiefly to the atmospheric pressure. In a vacuum, however, it occurs instantaneously, because the vapor then meets with no resistance. This phenomenon occurs in obedience to the following laws.

1st.—*All volatile liquids, in a vacuum, volatilize instantly.*

2d.—*At the same temperature the vapors of different liquids possess unequal elastic force.*

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619. What is vaporization? What is evaporation? What is boiling? What solids vaporize without liquefaction? What happens when a liquid is changed to vapor?

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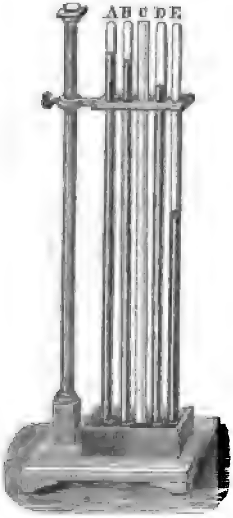

These laws are illustrated in the apparatus, fig. 339, where four barometer tubes, originally filled with pure dry mercury, are supported by the stand in a mercurial cistern, and will all indicate upon the scale, *C*, the same height of column. A drop of ether passed up to *E*, instantly flashes into vapor and depresses the column perhaps half its height or more, according to the quantity used. This illustrates the first law. A drop of bisulphid of carbon introduced into *D;* of alcohol into *B;* and of water into *A*, will also be respectively changed to vapor, wholly or in part, and will depress the mercury unequally, in the order of their volatility as enumerated. This illustrates the 2d law. If all the ether introduced into *E* has disappeared, then successive small portions may be added, and with each addition an increased depression of the mercury will be observed, until finally a point is reached where the ether remains liquid. This is the point of ***saturation*** or ***maximum tension*** of ether vapor for that temperature. A change of temperature will of course vary these conditions. If either of the tubes is surrounded by one of larger diameter dipping under the mercury, and so affording a cell into which hot water may be poured, the liquid ether in *E*, for example, will be vaporized, still further depressing the mercury, according to the temperature. If a freezing mixture were similarly used, the reverse would be seen—a portion of vapor would be liquefied.

621. **Saturated space or maximum tension of vapors.**—The meaning of these terms may be still further illustrated by the use of the apparatus seen in fig. 340, which is provided with a well, filled with mercury, and deep enough to allow the tube to be depressed nearly its whole length.

Suppose the tube to have the condition of *E* in the last paragraph, that is, the vapor of ether has nearly filled the whole tube, and is at its point of saturation or maximum tension. If the tube is

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Give the example from the boiling of water. 620. Why does evaporation occur slowly in the open air? What is said of evaporation in a vacuum? What are its laws? How are these laws illustrated? Explain fig. 339. To what extent may vaporization of ether in *E*, occur? 621. How may the terms saturated space and maximum tension be further illustrated? Explain the use of the apparatus, fig. 340. What result follows?

now depressed, the contained vapor is subject to increased pressure in proportion to the amount of depression and the result is, that a portion of it takes on the liquid form, and the mercury takes the place of the vapor. If the tube is raised, then the pressure is again diminished, and a fresh portion of ether is vaporized. There is therefore a maximum tension or elasticity for the vapor of different liquids at every temperature, so that in a saturated space at a given temperature, the maximum tension is the same, whatever may be the pressure to which the vapor is subjected.

622. Dalton's law of the tension of vapors is as follows.

The tension or elasticity of different vapors is equal if compared at temperatures the same number of degrees above or below the boiling point of their respective liquids.

This law does not perfectly accord with the results of experiment, but it is nearly correct, (with the exception of mercury,) at short distances above and below the boiling point.

The tension of vapors at equal distances above and below the boiling point of their respective liquids, is shown in the following table condensed from Miller.

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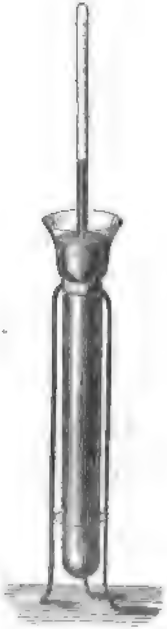

Number of degrees above or below boiling.	Regnault.		Ure.		Ure.		Marx.		Avogadro.	
	Water.		Alcohol. sp. gr. 0·813.		Ether.		sulph't carbon.		Mercury.	
	Temp. °F.	Pressure, inches.	Temp. °F	Pressure, inches.	Temp. °F	Pressure, inches.	Temp. °F	Pressure, inches.	Temp. °F	Pressure, inches.
+40°	252	63·14								
+20°	232	44·06			124	42·64	137	40·19		
Boil. p't.	212	30·00	173	30·00	104	30·00	117	29·87	680	30·00
—20°	192	19·87	153	19·30	84	20·90	97	20·65		
—40°	172	12·78	133	11·60	64	13·00	77	13·89	630	19·85
—60	152	7·94	113	6·70	44	8·10	57	9·07		
—80	132	4·67	93	3·67			37	5·73	590	14·08

623. The tension of vapors in communicating vessels unequally heated is the same, and is equal to the lower temperature.

Thus if a vessel containing water at 32° communicates by a tube

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622. What is Dalton's law of the tension of vapors? What is shown by the table?

with a vessel in which the water is boiling, the pressure in both of the vessels will be the same, as may be ascertained by a manometer. This is explained by the condensation which the vapor constantly suffers in the colder vessel. Application is made of this principle in the condenser of the steam-engine.

624. **Temperature and limits of vaporization.**—The vaporization of liquids takes place at temperatures much below their boiling points, as common experience testifies. Even at the ordinary temperature of the air, water, and many liquids and some solids vaporize.

Even mercury, whose boiling point is 662°, evaporates at all temperatures above 60° F., as was proved by Faraday. He suspended from the cork of a flask containing mercury, a slip of gold leaf. After six months, the gold leaf was found to be whitened by the mercury which had risen in vapor. A dew of metallic globules is sometimes seen in the Torricellian vacuum. Iodine, camphor and other solids, rapidly evaporate at the ordinary temperature. Snow and ice disappear from the surface of the earth during cold weather when there has been no thawing. Boyle found that two ounces of snow, in a very cold atmosphere, lost ten grains in six hours.

The experiments of Faraday, however, appear to show that vaporization does not occur at all temperatures.

Thus mercury gives off no appreciable vaper below 60°. Sulphuric acid undergoes no appreciable evaporation at ordinary temperatures. Faraday proved that several substances which are volatilized by heat at temperatures between 300° and 400° did not suffer the slightest evaporation when kept in a confined space at the ordinary temperatures during four years.

The limit of evaporation is reached when the cohesive force of the particles of the solid or liquid overcomes the feeble tendency to evaporation.

625. **Circumstances influencing evaporation.**—Evaporation, as has been said, is the slow production of vapor from the surface of a liquid. The elastic force of a vapor which saturates a space containing a gas, (like air,) 348, is the same as in a va-

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623. What is the tension in communicating vessels unequally heated? Illustrate this. In what case is this principle applied? 624. What is said of the temperature of vaporization? Give examples. What is said of mercury? Give examples of solids. What was Boyle's observation? What do Faraday's experiments show as to a limit to evaporation for mercury and sulphuric acid? What determines the limit of evaporation? 625. What is said of the elastic force of vapor in air and in a vacuum?

cuum. The principal causes which influence the amount and rapidity of evaporation are as follows.

1st.—*Extent of surface.* As the evaporation takes place from the surface, an increase of surface evidently facilitates evaporation.

In all cases in the arts where rapid evaporation is the object, shallow pans of large surface are employed, as in the salines of Syracuse and elsewhere. The evaporating surface may be enormously increased, as in the salt works of the Tyrol, by allowing the brine to trickle down over brush wood stacked closely in square piles.

A film of oil on the surface of a liquid greatly retards evaporation, an expedient often used in the laboratory.

2d. *Temperature,* by increasing the elastic force of vapor, has a most important influence on the rapidity of evaporation; therefore the temperature of ebullition marks the maximum point of evaporation.

3d.—*The quantity of the same liquid already in the atmosphere* exercises an important influence on evaporation. The atmosphere can dissolve but a certain amount of vapor, and evaporation entirely ceases when the air is saturated, and is greatest when it is free from vapor.

4th.—*Renewal of the air.*—If currents of air are continually removing the saturated atmosphere from above the surface of a liquid, evaporation takes place most rapidly, since new portions of air, capable of absorbing moisture, are presented to it. Evaporation is therefore more rapid in a breeze than in still air.

5th.—*Pressure on the surface of the liquid* influences evaporation, because of the resistance thus offered to the escape of the vapor.

Prof. Daniell, from a series of researches on the rate of evaporation, deduced the following law, viz:

The rapidity of evaporation is inversely as the pressure upon the surface of the evaporating liquid.

626. **Dew point.**—If air saturated with moisture is cooled, a portion of the moisture will be precipitated as dew. The temperature at which this deposition of moisture commences, is called the *dew point.* The dew point is nearer the temperature of the atmosphere, the more fully the air is saturated with moisture.

Illustrate the influence of surface on evaporation? How does a film of oil act? What is the second condition influencing evaporation? What is the third? What the fourth? How does pressure influence evaporation? What is the 5th law of evaporation? What is the law deduced by Daniell? 626. What is the dew point?

The methods of determining the amount of moisture contained in the atmosphere will be described in the chapter on Meteorology.

627. **Ebullition.**—The elasticity of the vapor from a boiling liquid is equal to the pressure of the superincumbent atmosphere.

When water is boiled in a glass vessel, the phenomena of ebullition may be distinctly seen. On first heating a liquid, the dissolved air (352) is expelled in small bubbles. As the heat is continued, bubbles of transparent and invisible steam are formed in the lower part of the vessel where the heat is applied. These grow smaller and smaller as they rise, and finally condense in the colder liquid with a series of little noises, producing what we call simmering. After a time, when the mass of liquid attains a nearly uniform temperature, these bubbles increase in size as they rise to the surface, owing to the evaporation from their interior surfaces as well as from the less pressure to which they are there subjected. As they reach the external air, at the surface of the liquid, they condense in a cloudy vapor, which is commonly called steam, but which in reality is water in exceedingly minute globules.

When a liquid has reached the boiling point, a comparatively small quantity of heat maintains it at that temperature. Water or any other liquid boiling moderately has the same temperature as when it is in violent ebullition. The excess of heat only causing a more rapid evaporation of the water.

628. **Table of boiling points.**—Every liquid has its own boiling point. In this table are given the boiling points of several fluids according to the latest authorities, and reduced to the atmospheric pressure of 29·92 inches.

	Temp. °F.		Temp. °F.
Sulphurous acid,	17°·6	Nitric acid,	241°·3
Chlorid of ethyl,	51 ·9	Bichlorid of tin,	240 ·2
Aldehyd,	69 ·4	Fousel oil,	269 ·8
Ether,	94 ·8	Terchlorid arsenic,	273 ·0
Bisulphid of carbon,	118 ·5	Butyric acid,	314 ·6
Terchlorid of silicon,	138 ·2	Sulphurous ether,	320 ·0
Bromine,	145 ·4	Oil of turpentine,	568 ·5
Wood spirit,	149 ·9	Sulphuric acid,	589 ·2
Alcohol,	173 ·1	Linseed oil,	597 ·0
Dutch liquid,	184 ·7	Mercury,	652 ·0
Water,	212 ·0		

627. What determines the elasticity of vapor? Explain the phenomena of boiling as seen in glass? What is simmering? What causes agitation in a boiling liquid? What is said of the quantity of heat required to keep water in ebullition? Why is this? 628. Give the boiling point of some of the more common fluids in the table.

629. **Influence of adhesion on the boiling point.**—The boiling point of water in vessels of different materials varies somewhat, owing probably to the different degrees of adhesion between the liquid and the surface of the vessels.

In a metallic vessel, water boils at 210° and 211°. If a glass vessel be coated inside with shellac, water boils in it at 211°. But if it be thoroughly cleaned with sulphuric acid, water may be heated in it to 221° or more without the escape of bubbles. A few grains of sand, a little fragment of wire, or a small piece of charcoal, will at once equalize these differences and cause the water to boil steadily at 212°.

From Dulong's experiments it appears that air in solution greatly assists the formation of vapor. By long boiling, the air becomes nearly expelled. When this was the case, the temperature was found to rise sometimes as high as 360° in an open glass vessel, which was then shattered with a loud report by a sudden burst of vapor.

630. **Influence of solids in solution on the boiling point.**—Solids dissolved in liquids raise their boiling points in proportion to the quantity dissolved. Thus a saturated solution of common salt boils at 227° F.; of nitre at 240°; of carbonate of potash at 275°, and of carbonate of soda at 220°. This is probably owing to the adhesion existing between solids and liquids which opposes itself to the repulsive force of heat. The vapor rising from boiling solutions has only the temperature of steam from pure boiling water in free air.

631. **Influence of pressure on the boiling point.**—As ebullition consists in the rapid formation of vapor of the same elasticity as the superincumbent atmosphere, it is evident, that if the pressure is diminished, the boiling point will be lowered, and if it be increased, that the boiling point will be raised.

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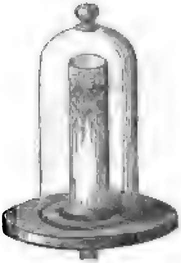

The influence of pressure on the temperature of ebullition is strikingly shown by placing a vessel of water, which has cooled considerably below the boiling point, beneath the receiver of an air-pump and exhausting the air, fig. 341. As the air is removed, the water enters into violent ebullition, even at a temperature of 125°. Liquids generally boil in vacuo at a tempera-

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629. What conditions influence boiling and why? Give some examples. What is the effect of dissolved air on the boiling point? 630. How do dissolved solids affect the boiling point? What is the temperature of steam from such? Give the boiling points of brine, nitre, &c.

ture of from 70° to 14° below their point of ebullition under the ordinary atmospheric pressure.

The following table from Regnault shows the temperature at which water boils under different pressures, represented by the corresponding heights of the barometric column. These results have been confirmed by direct observation.

Boiling point, °F.	Barometer, inches.	Boiling point, °F.	Barometer, inches.
184	16·676	200	23·454
186	17·421	204	24·441
188	18·196	206	25·468
190	18·992	208	26·529
192	19·822	210	27·614
194	20·687	212	28·744
196	21·576	214	29·922
198	22·498	302	31·120

632. **The culinary paradox** is a fine illustration of the phenomena of boiling under diminished pressures.

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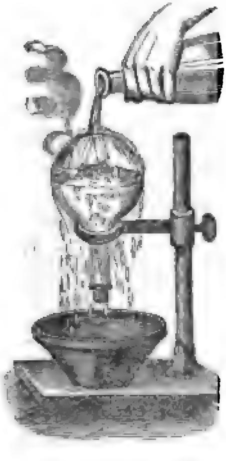

A small quantity of water is boiled in a glass flask until the steam has driven out the air. When the water is in active ebullition, a good cork is firmly inserted in the mouth, and the heat is removed. The flask is then supported in an inverted position, as is shown in fig. 342; with the mouth under water. The water still continues to boil more violently than when over the flame. If cold water be poured upon the flask, the ebullition becomes still more violent, but will be speedily arrested by the application of hot water.

The cause of this seeming paradox is plain. When the flask was corked, there was only the vapor of water above the liquid, the air being driven out by the previous boiling. By the application of cold water, a portion of this vapor becomes condensed, and the water within being under diminished pressure, boils at a correspondingly low temperature. But hot water thrown upon the flask

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631. How do changes of pressure influence boiling, and why? How is this shown by fig. 341? Give further illustrations from the table. 632. What is the culinary paradox? Explain the action of the flask with hot and cold water alternately, fig. 342. What is the pulse glass?

increases the elasticity of the vapor, and the water being thus subjected to a greater pressure, ceases to boil.

Franklin's pulse glass, a double bulbed glass, fig. 343, partly filled with ether and closed while boiling, boils from the heat of the hand, a sensible coolness being felt as the last portions of fluid rush out of the empty bulb, the hand furnishing the heat needed to vaporize the ether.

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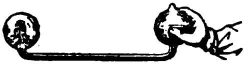

633. **Useful applications in the arts** are constantly made of the facts just explained, to concentrate vegetable extracts, sugar juice, &c., under diminished pressure, and consequently at a temperature below the point where there is any danger of injury from heat. Sugar is usually concentrated thus in large close copper vessels, called vacuum-pans, at a temperature of 150° F., aided by a powerful air-pump and condenser to remove the vapor rapidly. There is no economy of fuel by boiling under diminished pressure, as will be understood from what is said hereafter.

634. **Measurement of heights by the boiling point. Hypsometer.**—On ascending mountains the boiling point of liquids falls, because the atmospheric pressure is less, and inversely in descending into mines it rises. Accurate observations show, that a difference of about 596 feet in elevation produces a variation of 1° F. in the boiling point of water. The metastatic thermometer (514) is used in these observations.

M. Regnault has designed an apparatus called a hypsometer, fig. 344, for determining elevations by the boiling point of water. It consists of a copper vessel, *C*, containing water. This is surmounted by a brass cylinder which supports and incloses a thermometer. The upper part of this cylinder is formed in pieces, *t*, which slide into each other like the tubes of a telescope, and serve to confine the steam about the thermometer tube, as in fig. 296. Air is supplied to the lamp, *l*, by the holes, *o, o*. The steam escapes by a lateral orifice in the upper part of the instrument.

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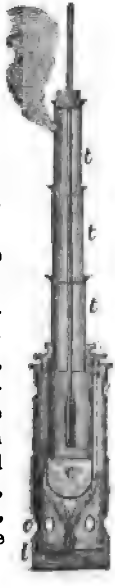

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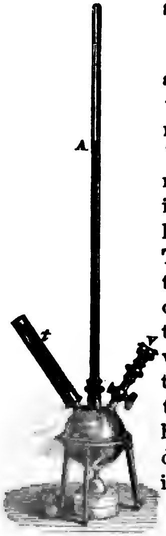
633. What use is made of these facts in the arts? Is there economy of fuel in this? 634. How is the boiling point affected by changes of level? What elevation corresponds to one degree? What thermometer is used and in what manner? Describe the appt. fig. 344.

In the following table is given the boiling point of water at different places, with their corresponding elevation above the level of the sea.

Names of places.	Above the level of the sea.	Mean height of the Barometer.	Thermometer.
	Feet.	Inches.	Degrees.
Farm of Antisana, S. A.	13,455	17·87	187·3
Micuipampa, (Peru,)	11,870	19·02	190·2
Quito, ...	9,541	20·75	194·2
Mexico, ...	7,471	22·52	198·1
Hospice of St. Gothard,	6,808	23·07	199·2
Madrid, ...	1,995	27·72	208·0
Salzburg, ...	1,483	28·27	209·1
Plombières, ...	1,381	28·39	209·3
Moscow, ...	984	28·82	210·2
Vienna, ...	436	29·41	211·1
Rome, ...	151	29·76	211·6

635. High pressure steam.—The boiling point rises as the pressure increases. This fact is readily demonstrated by Marcet's apparatus.

345.



A spherical boiler is supported over a lamp upon a tripod of brass, fig. 345. A thermometer, *t*, enters the upper hemisphere, and its bulb is exposed directly to the steam. A stop-cock and safety valve, *V*, opens a communication to the outer air. A manometer tube, *A*, with confined air (347) descends into some mercury placed in the boiler, (whose lower hemisphere is for that reason made of iron.) The boiler is filled with water to the equator. When the water boils and the air has been expelled, the open stop-cock is closed and the steam commences to accumulate. The thermometer, which stood previously at 212°, begins to rise higher and higher as the column of mercury rises in the gauge. When the mercury has risen in the gauge a little less than half the height of the tube, the thermometer will indicate 249° ·5 F., and so on according to the following table, after the late results of M. Regnault.

Give the temperature for some places in the table. 635. How does pressure affect the boiling point? What is Marcet's apparatus? Describe its action. What temperature corresponds to one atmosphere? What to two, five, to ten, to twenty atmospheres? What limit is there to the temperature attainable by pressure?

Pressure in atmosphere of 30 inches mercury.	Temp. F.	Pressure in atmospheres of 30 inches mercury.	Temp. F.
1	212°	11	364°2
2	249 ·5	12	371 ·1
3	278 ·3	13	377 ·8
4	291 ·2	14	384 ·
5	306 ·0	15	390 ·
6	318 ·2	16	395 ·4
7	329 ·6	17	400 ·8
8	339· 5	18	405 ·9
9	348· 4	19	410 ·8
10	356· 6	20	415 ·4

It is evident from this table that steam may be obtained of any temperature, provided we have vessels of sufficient strength to withstand the corresponding pressure. Thus Mr. Jacob Perkins obtained steam from a very strong boiler, so hot as to fire tow and other combustible bodies, and the pipes conveying hot water under a great pressure, according to his system, have been known to fire buildings. (See *warming*.) The water and the steam from it, under pressure, have always the same temperature. An empty vessel, or one filled only with steam, is soon destroyed by heat, but as long as water remains in the vessel, heat cannot accumulate to an injurious extent, being absorbed in the production of steam. Thus water is boiled in wooden vessels by steam-pipes, and even in case of fires, wooden tanks full of water have remained uninjured by the fire, while the water within was boiling.

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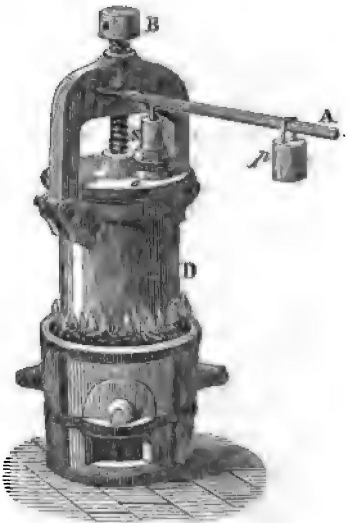

Advantage is taken of the temperature of high steam in the arts

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What did Perkins obtain? What is the comparative temperature of water and steam under pressure? Why does not heat destroy a vessel containing water? What is said of wooden tanks?

to extract gelatine from bones, and to perform other difficult solutions and distillations which, at 212° would be impossible. Papin, a French physicist, who died in 1710, first studied these effects of high steam with the apparatus seen in figure 346, known as Papin's digester. It is only a boiler, *D*, of great strength, provided with a safety valve, *S*, (here first used,) and gallows screw, *B*, to secure its cover, *o*.

636. **Production of cold by evaporation.**—A liquid grows sensibly colder, if while evaporating it does not receive as much heat as it loses, and the more sensibly so, as the evaporation is more rapid.

Eau de cologne, bay-rum, or ether, evaporating from the surface of the skin, produce very sensible coldness, due to the rapid absorption of the bodily heat in the evaporation. Portions of body may be thus benumbed to insensibility to pain during surgical operations.

A summer shower cools the air by absorbing heat from the earth and the air during evaporation. Curtains wet with water, leafy branches of trees, mossy banks, and fountains draped by climbing plants, are cool for the same reason. Fanning the surface produces coolness both from conduction and evaporation. Wet clothes are pernicious, chiefly from the rapid loss they cause of animal heat during evaporation, thus impeding the circulation. In hot climates, where ice is rare, water is cooled to an agreeable temperature by the use of jars of porous earthenware placed in a draught of air. The surface moisture is rapidly evaporated by the dry air, and the water in the vessels falls 20 or 30 degrees below the exterior air, even at 80 or 90 degrees. Water is readily frozen in a thin narrow test-tube by the constant evaporation of ether from a muslin cover drawn over the outside of the tube. In the East Indies, water is frozen by its own evaporation, aided by radiation, in cool serene nights, when the external air is not below 40°. For this purpose shallow earthen pans are used, placed in a slight pit or depression of the earth upon straw to cut off terrestrial radiation. (575.) Water is endowed with a remarkable emissive power, and will, as shown by Melloni, lose 7° below the atmosphere by simple radiation in serene nights. Compared to this remarkable Indian result, Leslie's experiment of freezing water in the vacuum of an air-pump, (over sulphuric acid to absorb the vapor, fig. 347,) seems simple;

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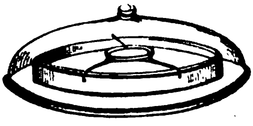

What use is made of these facts in the arts? Describe Papin's digester. 636. Why does evaporation produce cold? Give illustrations. Why does a shower cool the earth? Why are wet clothes injurious? Why and to what degree do porous jars cool water? How is water frozen by the evaporation of ether? How is it frozen in India when the external air is not below 40°?

and easier still is the same effect produced in the cyophorus (or *frost-bearer*) of Dr. Wollaston, fig. 348, where a portion of water in one

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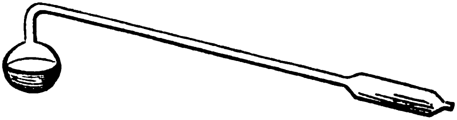

bulb of a vacuous glass tube is frozen by its own rapid evaporation due to cooling the empty bulb in a freezing mixture.

An apparatus has been successfully contrived by Prof. Twining for producing ice upon a commercial scale in those hot climates where it cannot be carried from colder countries, by the rapid evaporation of a portion of ether confined in chambers contiguous to the water vessels —the process, by aid of an air-pump and condenser, being continuous and without sensible loss of ether.

637. **Latent heat of steam.**—A large amount of heat disappears or is rendered latent during evaporation. According to Regnault, the latent heat of steam is 967°·5. Its determination is made in a number of ways.

If a vessel containing water at the temperature of 32° is placed over a steady source of heat, it receives equal additions of heat in equal times. Let the time be noted that is required to raise the temperature to 212°. If now the heat is continued until all the water is converted into steam, it will be found that the time occupied in the evaporation was 5½ times that required to heat the water through the first 180°, *i. e.*, from 32° to 212°. Consequently 5½ times as much heat is absorbed during the evaporation of water as is required to bring it to boiling point. The latent heat of steam is therefore about (180° × 5½) 990°.

Again, the latent heat of steam is determined by distilling a certain amount of water and condensing the steam in a large volume of the same liquid. If the temperature be noted before and after the experiment, it will be found that the heat from the steam formed from a pound of water, was sufficient to raise the temperature of ten pounds of water 99°. The latent heat of steam is therefore again found to be (99° × 10) 990°.

Experiments conducted in the simple manner just mentioned cannot be entirely accurate, owing to a certain loss of heat by vaporiza-

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Give the philosophy of this result. What is Leslie's experiment? What use has the sulphuric acid in fig. 347? Explain Wollaston's cyophorus. How have these principles been applied by Twining? 637. What is meant by the latent heat of steam? How much is it? How is this determined by a simple experiment? How by distillation? What errors exist in these results?

tion, conduction and radiation. Numerous precautions are therefore to be adopted to insure the accuracy science demands in such an investigation, the details of which are inconsistent with our limited space.

The latent heat of steam obtained by different experimenters, varies somewhat as follows:—Watt, 950°; Lavoisier, 1,000°; Despretz, 955°·8; Brix, 972°; Regnault, 967°·5; Fabre and Silbermann, 964°·8.

638. **Latent and sensible heat of steam at different temperatures.**—The whole amount of heat in steam is the *latent heat*, plus the *sensible heat*. Thus the heat of steam at the temperature of ebullition is 967°·5 + 212° = 1179°·5. It has heretofore been generally stated, that the heat absorbed in vaporization is less as the temperature of the vaporizing liquids is higher. So that if the sensible heat of steam at any temperature is subtracted from the constant 1179°·5, the remainder is the latent heat of steam at that temperature. For example: the latent heat of steam at 279°·5, is 900°, at 100°, 1079°·5, &c. This statement however is found to be somewhat inaccurate, although in practice it may be assumed to be nearly correct.

From the experiments of Regnault, it appears that the sum of the latent and sensible heat increases with the temperature by a constant difference of 0°·305 for each degree F., as is shown in the following table.

Temp.	Latent heat.	Sum of latent heat and sensible heat.		Latent heat.	Sum of latent heat and sensible heat.
32°	1092°·6	1124°·6	248°	939°·6	1187°·6
68	1067 ·4	1135 ·4	284	914 ·4	1198 ·4
86	1054 ·8	1140 ·8	320	889 ·2	1209 ·2
104	1042 ·2	1146 ·2	338	874 ·8	1212 ·8
140	1017 ·0	1157 ·0	374	849 ·6	1223 ·6
194	979 ·2	1173 ·2	410	822 ·6	1232 ·6
212	966 ·6	1178 ·6	446	995 ·6	1241 ·6

639. **Mechanical force developed during evaporation.**—During the conversion of a liquid into vapor, a certain mechanical force is exerted. The amount of this force depends on the pressure

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Give the latent heat of steam according to several authorities. 638. What is the whole amount of heat in steam? How has this been generally stated? Give an example. What correction have the results of Regnault supplied? What is the co-efficient of correction for each degree F.? 639. What is developed during evaporation?

of the vapor and the increase in volume which the liquid undergoes.

Equal volumes of different liquids produce unequal amounts of vapor at their respective boiling points.

1	cubic	inch of	water	expands	into	1696	cubic	in.	vapor	at	b. point·
1	"	"	alcohol	"	"	528	"	"	"	"	"
1	"	"	ether	"	"	298	"	"	"	"	"
1	"	"	turpentine		"	193	"	"	"	"	"

Now although the latent heat of equal weights of other vapors is less than that of steam, yet no advantage would arise in generating vapor from them in place of water in the steam-engine. For equal volumes of alcoholic and aqueous vapor contain nearly the same amount of latent heat at their respective boiling points, and such is the case to a great extent with other liquids. The cost of the fuel in generating vapor would be in proportion to the amount of latent heat in equal volumes of the vapor.

11.—*Condensation of vapors and gases.*

640. **Liquefaction** of vapors, or the conversion of vapors into liquids, is accomplished in three ways. 1st, by cooling; 2d, by compression; and 3d, by chemical affinity. Only the two first of these methods will be spoken of. When vapors or gases are condensed into liquids, the same amount of heat is given out as sensible heat which was absorbed and rendered latent when they assumed the æriform condition.

641. **Distillation is the successive evaporation and condensation of liquids.**—The process depends on the rapid formation o vapor during ebullition, and the condensation of the vapor by cooling.

Distillation is used, first, for the separation of fluids from solids, as the distillation of ordinary water, to separate the impurities contained in it; 2d, for the separation of liquids unequally volatile, as in the distillation of fermented liquors, to separate the volatile spirits from the watery matter.

642. **Alembics.**—Distilling apparatus of various kinds are em-

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Upon what does the amount of force depend? Give the volumes of vapor produced by a cubic inch of water, alcohol, &c., respectively. Why is there no advantage in steam power from liquids of low boiling point? What determines the cost of fuel? 640. How are vapors condensed into liquids? How much heat is evolved in this process? 641. What is distillation? What is it used for?

ployed in the arts, according to the special purpose to which they are applied. The alembic, fig. 349, is the most ancient; its invention is attributed to the Arabs. It consists of three parts; first, the boiler or still, *C*; second, the head or dome, *c*; and third, the condenser or worm, *R*, *S*, *r*.

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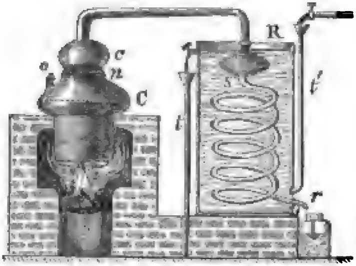

The liquid to be distilled is placed within the boiler, which is made of copper or of iron, and is heated by the fire beneath. The head is made of such a shape, that any portion of the liquid mechanically carried over with the vapor, is restored to the boiler. The worm into which the vapor passes is a spiral tube, contained in a vessel of cold water, whereby the vapor is condensed and flows into the receiving vessel, *r*. As the water is rapidly warmed by the latent heat evolved, from the condensed vapor it must be continually renewed. By means of the tube, *t'*, the cold water is introduced at the bottom of the vessel, where the vapor should be perfectly condensed, and the warm water rising, escapes through the outlet tube, *t*. With this apparatus the ordinary distillations are carried on in the large way.

643. **Retort and receiver.**—Where small quantities of liquids are to be distilled, as in the ordinary operations of the laboratory, retorts or flasks are used.

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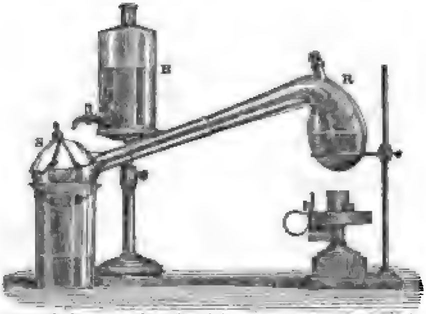

Retorts are vessels of glass, sometimes of porcelain or earthenware, and of the shape represented by fig. 350, *R*. The heat of a lamp may be applied to the naked glass if the retort contains only water; but if a denser fluid is used, then it is always safe to protect the glass by a sheet iron pan containing sand. In this way, even sulphuric acid and mercury may

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642. What is the alembic? Describe fig. 349. How is it used?
643. What is a retort? Describe the apparatus, fig. 350.

be safely boiled in glass. In other cases, where it is desired to avoid a heat above 212°, the retort is heated through the medium of a water-bath.

The receiver may consist of a simple flask attached to the neck of the retort, as represented by *S.* The cooling is effected by water from a faucet, dropping continually on a cloth or paper wrapped around it. This arrangement is sufficient where the vapor is quite easily condensed, but where volatile liquids are distilled, other means of condensation must be resorted to. The most efficient apparatus for laboratory use is,

Liebeg's condenser, fig. 351, is a glass condensing tube, *A A'*, surrounded by a larger tube, *B*, of metal or glass, and mounted on a foot.

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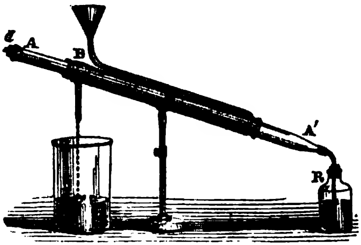

A funnel conveys cold water from a reservoir to the lower end of the encasing tube, and the escaping warm water flows from the delivery tube into a vessel beneath. The vapors to be condensed arrive from the flask or retort, by the tube, *d*, and meeting the cold walls of the condensing tube, are liquefied and flow into the receiver, *R.*

A similar arrangement was employed by Lavoisier and Laplace in their experiments upon calorimetry.

644. **Fractional distillation.**—Liquids of different volatility, as water and alcohol, the various ethers and essential oils, when mingled, are separated by what is called *fractional distillation.*

In the laboratory this is conducted by changing the recipient from time to time, as the boiling points and specific gravities of the liquids may indicate. In the arts, however, alcoholic and other liquids are concentrated by a single distillation, by the use of an apparatus consisting of successive chambers, in which the products condense in the inverse order of their volatility, and the latent heat set free by the condensation of the more condensible is made to maintain the more volatile in vapor for the next compartment, &c. In distilleries this is called distillation with a column. (Derosne's apparatus.) Adams' condenser is another similar contrivance.

What is Liebeg's condenser, fig. 351, and how is it employed? 644. What is fractional distillation? How is it employed in the arts?

645. **Physical identity of gases and vapors.**—The difference between gases and vapors is merely one of degree. Their identity in many of their physical properties has already been shown. Thus the ratio of their expansion by heat is the same as that of the permanent gases. A permanent gas may be considered as a *super-heated vapor;* the vapor of a liquid which volatilizes at very low temperatures. Gases, like vapors, may be condensed into liquids, and by very similar processes.

646. **Theory of the liquefaction and solidification of gases.**—As a gas is a super-heated vapor, if the excess of heat is removed, the gas is in the same condition as an ordinary vapor, containing only sufficient heat to maintain it in the æriform condition. By the compression of a gas, heat is evolved, either by diminishing its specific heat or by rendering sensible the heat before latent. If the compressed gas is then surrounded by a freezing mixture, the further abstraction of heat causes the condensation into a liquid of a corresponding portion of gas. It is thus by condensing and cooling gases, that their liquefaction and solidification have been effected.

647. **Carbonic acid.**—Before describing the means used to liquefy and solidify the different gases, a few words may be said of carbonic acid, and the methods of preparing effervescent drinks.

Carbonic acid is a colorless gas having a slight odor and perceptibly sour taste; its density is one and a half times that of air. (den. 1·529.) It is easily prepared by adding sulphuric or chlorohydric acid to carbonate of lime, carbonate of soda, or any other carbonate. Carbonic acid is soluble in water, and to whatever pressure it may be subjected, water will absorb but an equal volume. Thus under the ordinary pressure of the atmosphere it will absorb one volume; if the gas be subjected to the pressure of two or three atmospheres, it will also absorb one volume. But under these pressures the gas will be compressed accordingly, so that an equal volume will contain two or three times as much gas as under the ordinary pressure.

Water, which has been charged under pressure with carbonic acid, forms the so-called soda-water. When the pressure is removed, the water is not capable of holding in solution so much of the carbonic acid as before, and the gas escapes in torrents of small bubbles. This is called effervescence. During the manufacture of champagne, carbonic acid is generated in large quantity in the liquid by fermen-

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645. What is the difference between gases and vapors? How may gases be defined? 646. What is the theory of liquefaction and solidification of gases? How may this be practically accomplished?

tation. As soon as the wires confining the cork are cut, the cork flies out with an explosion, and the excess of gas escapes with effervescence.

648. **Soda-water apparatus.**—Apparatus for preparing soda-water and other effervescent drinks, are of various forms. They are all constructed upon the principle of generating the carbonic acid in a confined space, in communication with a closed vessel containing water.

Fig. 352 represents a closed metal or strong glassware vessel, divided into two compartments, *A* and *B*. A lateral tube, *a b*, allows communication between the two. A mixture of bicarbonate of soda, five parts, and tartaric acid four parts, in dry powder, is put into *A*, and the aperture, *o*, is closed. *B*, is filled entirely full with water, and the cap, *n*, and tube are screwed in. The tube, *a b*, allows as much water to flow into *A*, as corresponds to the space above *a*. As soon as the water reaches the powders in *A*, chemical action commences, and the carbonic acid gas is forcibly condensed in contact with the water in *B*, which is thus saturated. After some hours, effervescent water may be drawn from the cock, *v*, the tube *p*, *i* descending to the bottom of the upper vessel. Artificial champagne is thus prepared from still-wines, with the addition of sugar-candy, and artificial mineral-waters, also, by placing the proper ingredient in *B*.

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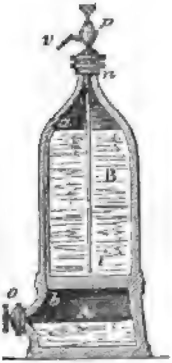

Breit has contrived a much neater apparatus for this purpose, composed of two egg-shaped glass vessels, covered by basket-work, but identical in principle with the above.

The *soda-fountains* of our cities are supplied with strong metallic vessels of copper or iron, which are charged by a forcing-pump similar to fig. 357, driven by a steam-engine.

The term *soda-water*, is usually a misnomer for gaseous water, and soda is seldom an ingredient of it.

649. **Faraday's tubes.**—In 1823, Faraday liquefied chlorine, cyanogen, ammonia, carbonic acid, and some other gases, by the following simple means.

For this purpose the materials from which the gas was to be evolved, provided they were solids, were placed in a strong glass tube, bent at an obtuse angle near the middle, fig. 353, and the open ends hermeti-

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647. What is carbonic acid? How is it prepared? How much of it can water absorb? What is the effect of pressure? What is effervescence?

cally sealed. Heat was then applied to the end containing the materials, (*e. g.* cyanid of mercury,) while the empty end was cooled in a freezing mixture. The pressure of the gas evolved in so small a space, united with the cold, liquefied a portion of it. Otherwise, if fluids were to be employed, the tube had the shape seen in fig. 354. The fluids were introduced by the small funnel *o*, *n*, into the curves *c* and *b*, and the ends, *a*, *d*, were then sealed by the blow-pipe. By a simple turn of the tube, all the fluid contents are transferred to the end, *a*, fig. 355, and the empty end, *d*, is placed in a freezing mixture where the liquid gas collects. Any fluid which distils over from *a*, collects in the bottom of the middle curve. A minute manometer was introduced by Faraday into these tubes, in order to determine the pressure at which liquefaction occurred. The manometer was a small glass tube sealed at one end, and holding a drop of mercury; the mode of reading the pressure has been before explained, (347.)

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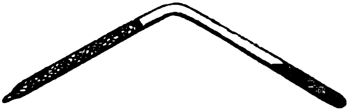

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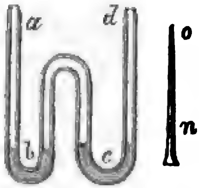
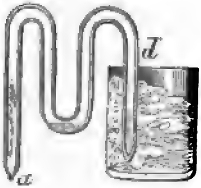


Great danger of explosion attended the use of these tubes; and to avoid this, and at the same time to obtain larger supplies of the liquid gas in a manageable shape; Thilorier, in France, and Mitchell, in the U. S., devised an apparatus of iron.



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650. **Thilorier's apparatus**, for liquefying and solidifying carbonic acid gas, although going out of use, (a much more desirable apparatus, Bianchi's, having been invented,) yet deserves mention as being the means by which large quantities of liquid carbonic acid were first prepared. Fig. 356 represents this apparatus in its essential details.

The generator of the gas is a strong cast iron vessel, *g*, hung by centres on a frame, *f*. In it is put the requisite quantity of bicarbonate of soda and water, and a copper tube, *a*, holding an equivalent amount of sulphuric acid. A cap of red metal is strongly screwed into the top of the vessel, and the position of the apparatus inverted by

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648. Describe the soda-water apparatus, fig. 352. What is the so-called soda-water? 649. What gases did Faraday liquefy and how? Explain the tubes, figs. 353, 354, 355. What danger is involved in their use? 650. What is Thilorier's apparatus?

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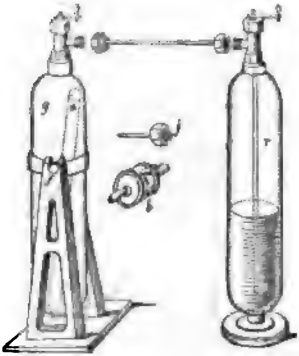

turning it over on its centres. The acid then flows from the tube upon the carbonate of soda, and an enormous pressure is exerted by the successive portions of carbonic acid gas evolved. In a few minutes the chemical action is complete, when the generator is connected by a metallic tube with the iron receiver, *r*, made very strong, and which is also surrounded by a freezing mixture of ice and salt. As soon as the stop-cocks are opened, the liquefied gas distils over into *r*. When the rush of the gas is no longer heard, the stop-cocks are closed, *g* and *r* are separated, and a fresh charge is introduced into the generator, and from thence into *r*, as before. In this way several quarts of liquid carbonic acid are accumulated in the receiver. The stop-cock of the vessel, *r*, is in communication with a tube which passes into the lower part of the receiver, so that when the stop-cock is opened, a jet of liquid acid is, by its own pressure, forced out. If a strong glass tube be properly refrigerated, a portion of the liquid acid may be safely drawn off into it. By securing the jet, *j*, to the reservoir, liquid acid may be made to play into a cylindrical box of brass, *b*, furnished with perforated wooden handles to allow the free passage of the gas. The rapid evaporation of a part of the liquid gas here absorbs so much heat from the rest, that a considerable portion is converted into a fine white solid, like dry snow, which fills the box. The properties of liquid and solid carbonic acid will be described in a succeeding paragraph.

From the enormous pressure exerted in the generator of this apparatus, the experiment is attended with considerable danger. A number of fatal accidents have resulted from the explosion of the generator. Thilorier's apparatus has in consequence been superseded by other forms of apparatus, in which gases can be liquefied without danger. The most successful of these, and now generally used, is—

651. **Bianchi's apparatus.**—M. Bianchi, under the direction of M. Dumas, has constructed an apparatus designed to compress gases by means of a force-pump. The figures 357, 358, represent this apparatus.

Through the tube *S*, fig. 357, the dried gas, (derived from a self-

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Explain its action from figure 356. What objection exists to it use? 651. What is Bianchi's apparatus?

acting reservoir,) enters the pump at *t*, fig. 358, which is connected with a wrought iron reservoir lined with copper.

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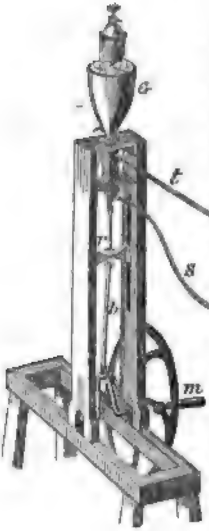

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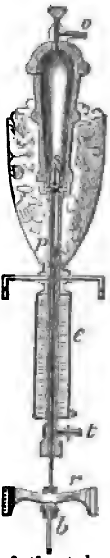

This cylinder has a capacity of about 700 c. m., and is capable of resisting a pressure of 600 or 700 atmospheres. A valve, *S*, fig. 358, prevents the compressed gas from rushing out of the cylinder. The piston rod, *b*, of the force-pump, (357,) passes the guide, *r*, and is moved by the hand wheel, *m*. The reservoir is refrigerated by an exterior vessel, containing ice or a freezing mixture. A stream of cold water circulates around the piston box in *e*, 358, which otherwise becomes heated in the working of the apparatus. The liquefied gas is removed by disconnecting the reservoir from the force-pump and opening the orifice at *O*. It is received into a glass tube surrounded by pumice-stone, moistened with sulphuric acid, in order to prevent the condensation of moisture in the interior of the tube. With this apparatus, even nitrous oxyd has been liquefied, and all danger of explosion is avoided.

652. **Liquid and solid carbonic acid.**—Liquid carbonic acid is colorless, like water, and has a density of 0·83. Its co-efficient of expansion is more than four times that of air. Twenty volumes of the liquid at 32°, becoming 29 volumes at 86°.

The solidified acid obtained by the evaporation of a portion of the liquid, appears in the form of snow; when congealed by intense cold alone, it is clear and transparent like ice. It melts at a temperature of —70° F. and is heavier than the liquid bathing it. The solid acid may be preserved for many hours if it be surrounded with cotton or some other poor conductor of heat. It gradually vaporizes without assuming the liquid form. The temperature of this solid, as determined by Faraday's experiments, is about 106° below 0° F. Although so intensely cold, it may be handled with impunity, and when thrown into water, the latter is not frozen. The cause of these re-

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Describe it from figs. 357, 358. 652. What are the properties of liquid carbonic acid? What of the solid? What is its temperature? Why can it be safely handled?

markable phenomena is, that the solid acid does not come in absolute contact with the hand or water, because rapidly evaporating, it is constantly surrounded by an atmosphere of its own vapor, which is a bad conductor of heat. By compressing the solid between the fingers, whereby direct contact is produced, the skin is destroyed as by a hot iron. By moistening it with ether, to which it has a strong adhesion, its low temperature is at once manifested. If mercury is placed in a wooden basin and covered with ether, and then solid carbonic acid be added, the mercury will soon be frozen. The temperature required to freeze the mercury is about —30° F. This frozen mercury may be drawn into bars, or moulded into bullets, or beaten into thin plates, if the operations be performed with wooden instruments.

653. **Later researches of Faraday.**—In 1845, Faraday published the results of his experiments on the liquefaction of gases by means of solid carbonic acid. With a mixture of this solid and ether in the vacuum of an air-pump, he obtained a temperature as low as —166° F.

In such a bath, at the ordinary pressure of the atmosphere, chlorine, oxyd of chlorine, cyanogen, ammonia, sulphuretted hydrogen, arsenirutted hydrogen, hydriodic acid, hydrobromic acid and carbonic acid, were obtained in the liquid form under moderate pressures. These liquids were colorless, with the exception of those from chlorine and oxyd of chlorine, which are colored gases in the ordinary state. A number of the liquefied gases were solidified. The solidified ammonia and sulphuretted hydrogen, resembled fused nitrate of ammonia; euchlorine appeared as an orange-colored crystalline solid; the other gases that were solidified, appeared in the form of clear transparent solids resembling ice, as was the case with carbonic acid. With the five gases, hydrogen, oxygen, carbonic oxyd, nitrogen, and nitric oxyd, which have the same co-efficient of dilitation as air, no signs of liquefaction were obtained by Faraday, although they were exposed to a cold of —166° F.; the first under a pressure of 27 atmospheres, the two last under a pressure of 50 atmospheres, and carbonic oxyd under a pressure of 40 atmospheres.

654. **Table of the liquefaction and solidification of gases.**—The following table gives the results of Faraday on this subject. The solids were usually heavier than the liquid from which they separated.

What effect has ether on it? How is mercury frozen by it and what is its character? 653. What results did Faraday obtain by it in 1845? What temperature did he obtain? What gases did he liquefy by this cold? What is said of the solid gases? What five gases resisted liquefaction, and at what temperatures and pressure?

Names of the gases.	Melting point °F.	Pressure in atmospheres.		
		at 32° F.	at 60° F.	°F.
Sulphurous acid,	—105°	1·53	2·54	5·16 at 100°
Cyanogen,	— 30	2·37	·	4·00 at 63
Hydriodic acid,	— 60	3·97	5·86	
Ammonia,	—103	4·4	6·90	10·00 at 83
Sulphuretted hydg'n,	—122	10·		14·60 at 52
Protoxyd nitrogen,	—150	32·		33·40 at 35
Carbonic acid,	— 70	38·5		
Euchlorine,	— 75			
Hydrobromic acid,	—124			
Fluorid of silicon,	—220			
Chlorine,		8·95	13·19	
Arseniuretted hyg'n,				
Phosphuretted "				
Olefiant gas,				22·90
Fluorid of boron,				11·54 at –62
Hydrochloric acid,				40·00 at 50

655. **Natterer's experiments.**—The most intense degree of cold that has as yet been obtained, was first produced by M. Natterer, by means of a bath composed of liquid protoxyd of nitrogen and bisulphid of carbon. He records a temperature of —220° F. Even at this low temperature, liquid chlorine and bisulphid of carbon, preserve their fluidity. Mercury, thrown into a bath of liquid protoxyd of nitrogen, (temperature —180° F.,) immediately solidifies.

In protoxyd of nitrogen gas, combustibles burn with nearly as great intensity as in pure oxygen; combustion also takes place in liquid protoxyd of nitrogen, notwithstanding the intense cold. A fragment of burning charcoal, thrown into this liquid, burns with brilliant scintillations, and thus almost at the same point there is a temperature of about 3600° above and 180° below zero.

656. **Variations from Mariotte's law.**—It has been stated, that according to Mariotte's law, the volume of a gas was inversely as the pressure to which it was subjected. Departures from this law are observed at the ordinary temperature, with the more easily condensible gases, as sulphuretted hydrogen and cyanogen, but it was most distinctly exhibited in the experiments of Caignard de la Tour, conducted as follows:

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654. What are the melting points and pressure of the several gases quoted? 655. Who obtained the greatest artificial cold, and how? What liquids were unaffected at this temperature? What is said of combustion in liquid protoxyd of nitrogen? 656. What departure from Mariotte's law has been observed, and by whom?

Strong glass tubes, furnished with interior manometer gauges, were partially filled with water, alcohol, ether and other liquids, and hermetically sealed. The temperature of the tubes was then gradually raised. Ether becomes a vapor at 328°, in a space equal to double its original bulk, exerting a pressure of 37·5 atmospheres; alcohol at a temperature of 404°·5, with a pressure of 119 atmospheres, and water disappeared in vapor, in a space four times its own bulk, at the temperature of about 773°. If Mariotte's law held good in these cases, the pressures exerted would have been very much greater than was actually observed. Even before a liquid wholly disappears, the elasticity of the vapor is found to increase in a proportion far greater than is the case with air at equally elevated temperatures. It is not therefore surprising that mere pressure fails to liquefy many bodies which exist ordinarily as gases. De la Tour announced the following law as the result of his experiments, viz:

There is for every vaporizable liquid a certain temperature and pressure at which it may be converted into the aeriform state, in the same space occupied by the liquid.

12.—*Density of vapors.*

657. **Gay Lussac's method.**—The accurate determination of the density of vapors is of great scientific importance, as it often throws light upon the composition of a body. Two methods have been proposed; the first is that of Gay Lussac, and is conducted as follows.

A graduated tube, *C*, fig. 359, filled with pure dry mercury, is placed in an iron vessel containing the same liquid. A weighed bulb of thin glass, *A*, is filled with the liquid whose vapor is to be determined and sealed. The bulb, after being again weighed, is then slipped under the edge of the tube. A glass cylinder, *M*, open at both ends, surrounds the tube, *C*, its lower end resting in the mercury, it is filled with water or oil. A thermometer, *T*, indicates the temperature at which the operation is performed. The heat applied to the kettle, is gradually communicated to the liquid in *M*, and the tube *C*. When the temperature rises to a certain height, the glass bulb is broken by the expansion of the liquid it contains, and the liquid quickly vaporizes, depressing the mercury in the tube. The volume of the vapor

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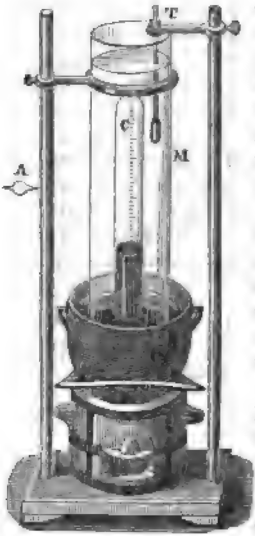
Give his mode of experiment. Give the pressures and temperature from ether, alcohol and water. What evidence is there here of non-conformity to Mariotte's law? What law did Caignard de la Tour announce? 657. By what two modes is the density of vapor determined? Describe Gay Lussac's from fig. 359.

is indicated by the number of divisions of the tube it occupies. The capacity of each of these divisions, at the ordinary temperature, being known, their capacity at the temperature, at which the operation is conducted, is calculated from the co-efficient of expansion of glass. The difference between the height of the barometric column and the mercury in the tube, indicates the pressure to which the vapor is subjected.

359



By calculating the weight of a volume of air, which under the same conditions of pressure and temperature occupies the same volume as the vapor under examination, and dividing the weight of the vapor by that of the air, the density of the vapor is obtained.

This method cannot be employed for liquids boiling at temperatures above 275°.

658. **Dumas' method.**—By Dumas' method, the density of vapors may be determined even when the boiling points of their liquids is as high as 650°; at higher temperatures ordinary glass softens.

This method consists, essentially, in filling a glass balloon with the vapor and weighing it; this weight, divided by the weight of an equal volume of air under the same circumstances, gives the density of the vapor.

The balloon of glass used, *B*, fig. 360, has a long slender neck, and a capacity of about half a litre, (1 pint.) After being cleaned and dried within and without, it is weighed, (*P*,) and a portion of the substance, whose vapor is to be determined, placed within it. The globe, supported in the manner shown in the fignre, is then immersed in the bath. This vessel contains saline solutions, oil, sulphuric acid, or some easily fusible alloy. The temperature of the bath is gradually raised to a point somewhat higher than the temperature of ebullition of the liquid within the bulb. When the liquid within the bulb has all vaporized, the neck is sealed, and the temperature of the bath and height of the barometer noted. After the balloon is cooled and cleaned,

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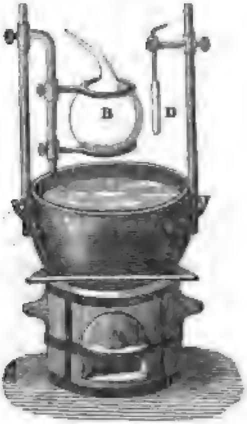
How is the result calculated? What limit has this method? 658. What is Dumas' method? Describe the apparatus, fig. 360.

it is again carefully weighed. (*P'*.) The end of the neck of the balloon is then broken off beneath the surface of mercury, which rushes up into the vacuum caused by the condensation of the vapor and fills it. This mercury is measured, and indicates of course the capacity of the balloon.

360



The first weight of the balloon, *P*,— the weight of the air it contained gives the weight of the glass, *P*, composing it. Subtracting this from the second weight, *P'*, there is obtained the weight of a volume of vapor equal to the capacity of the globe. The volume, temperature and pressure of the vapor being known, its density is easily ascertained, after determining the weight of a volume of air under the same circumstances.

SPHEROIDAL STATE.

659. **Spheroidal state.**—Drops of water scattered on a polished surface of heated metal do not immediately disappear, but assume the form of flattened spheres, rolling quietly about, until they gradually evaporate. If the metal has not a certain temperature, it is wetted by the water with a hissing sound. This observation was made in 1746, and ten years after, Liedenfrost called particular attention to the phenomenon. Döbereiner, Laurent and others, also experimented upon this subject. They found that saline solutions, as well as simple liquids, would act in the same manner as water. It is however to Boutigny, that we are particularly indebted for the investigation of the phenomena of the spheroidal state of liquids.

660. **Illustration of the spheroidal state.**—The above experiment may be variously performed, according to the ingenuity of the experimenter.

A small smooth brass capsule is heated over a lamp, fig. 361, and a few drops of water allowed to fall upon it from a pipette; the drops do not wet the metallic surface, but roll about in spheroidal globules,

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How is the result of the experiment calculated? 659. What is the spheroidal state? Who has investigated this subject? 660. Illustrate the facts by fig. 361.

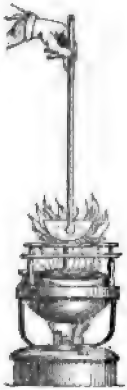
uniting together after a time, into a single mass, which, it will be seen, has the form of an oblate spheroid, and evaporates but slowly. This is the condition distinguished by Boutigny as the spheroidal state. If the metal is allowed to cool gradually, when the temperature falls to a certain point, the liquid will burst into violent ebullition and quickly evaporate.

361

The spheroidal state may be produced in a vacuum as well as in the air, upon the smooth surface of most solids, and also upon the surface of liquids.

661. **The temperature of bodies when in the spheroidal state** is always lower than their boiling points. This was determined by Boutigny by immersing a delicate thermometer in the spheroid, as shown in fig. 362.

362



Thus 205°·7 is the temperature of the spheroid of water; 167°·9 that of alcohol; 93°·6 that of ether; 13°·1 that of sulphurous acid.

The temperature of a spheroid is not quite as definite as the temperature of ebullition of the liquid, but rises somewhat as the plate upon which it rests is more intensely heated.

The temperature of the plate.—The temperature to which it is necessary to heat the plate, in order to produce the spheroidal state, varies with the boiling point of the liquid employed.

Thus with water the spheroidal state is produced when the plate is at a temperature of 340°, and may attain it even at 288°; with alcohol and ether, the plate must have at least the temperature of 273° and 142° respectively.

662. **Spheroidal state produced upon the surface of liquids.**—A highly heated liquid may cause the spheroidal state in another liquid of lower boiling point than itself.

Thus Pelouze found that water assumed the spheroidal state on very hot oil of turpentine, although the water is the denser liquid. Boutigny has thus sustained water, alcohol, and ether, on sul-

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How does the spheroid act? When the metal cools what happens? How else may this state be produced? 661. What is said of the temperature of bodies in this state? How is this demonstrated? What is said of the temperature of the plate? At what temperatures do water and alcohol become spheroidal? 662. How is it with liquids? What liquids have been thus [illegible] phuric acid nearly at its boiling point. With sufficient precautions a number of liquids may be thus piled one upon the other.

663. **The rapidity of evaporation** of bodies in this state increases with the temperature of the plate, as is proved by the following experiments of Boutigny. The same quantity of water, (0·10 gramme, or 1·534 grs.) was evaporated in each case.

With the plate at the temp. of 392°, the water evap. in 207 seconds.
" " " " " " " 752°, " " " " 91 "
" " " " dull red heat, " " " " 73 "
" " " " bright " " " " " " 50 "

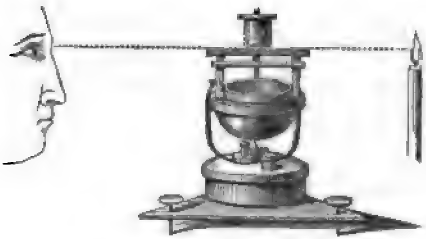
Water in the spheroidal state evaporates much more slowly at its temperature of ordinary ebullition. Thus when the plate was at the temperature of 212°, 0·10 grms of water evaporated in 4 seconds, and when at the temperature of 392°, in 207 seconds, or less than one-fiftieth part as rapidly.

664. **The temperature of the vapor** from a spheroid is nearly the same as that of the plate upon which it rests, which proves that the vapor is not disengaged from the mass of the liquid.

665. **A liquid in the spheroidal state is not in contact with the heated surface beneath.**—This must appear on reflection upon the facts already stated, and may be demonstrated as follows.

A horizontal silver plate is surmounted by a tube of the same metal, fig. 363, whose lower edges have two longitudinal slits opposite to each other. The plate is placed upon the eolipile, which is nicely adjusted to a perfect level by the screws in the triangular base. Silver is employed to avoid the formation of scales of oxyd of copper, which would ininterfere with the observation by interposing themselves to the light.

363



When the plate heated over the lamp reaches the proper temperature, a portion of water is placed upon its centre, and immediately assumes the spheroidal condition. Placing the eye on a level with

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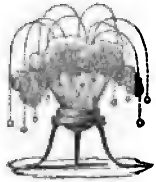
663. What is the rapidity of evaporation of bodies in this state? Give examples. How does it compare with the evaporation at boiling point? 664. What is the temperature of the vapor? 665. How is it proved that a liquid in this state does not touch the plate? Explain the experiment, fig. 363.

the surface of the plate, and looking through the apertures, in the sides of the tube, the flame of a candle opposite may be distinctly seen. This could not happen if the liquid was in contact with the plate. If a thick and heavy silver capsule is heated to full whiteness over the eolipile, it may by an adroit movement be filled entirely with water, and set upon a stand, some seconds before the heat declines to the point when contact can occur between the liquid and the metal. When this happens, the water, before quiet, bursts into steam with almost explosive violence, and is projected in all directions, as shown in fig. 364.

364



666. **A repulsive action is exerted between the spheroid and heated surface.**—This proposition follows indeed as a consequence of the last. It has already been demonstrated, that a liquid does not wet a surface, when the cohesion which exists between its particles is double of their adhesion for the solid. (289.) This adhesion is not only diminished by heat, but a repulsive action is exerted between the hot body and the liquid, which becomes more intense as the temperature is higher. This repulsive action is strikingly demonstrated by the following experiment of Boutigny.

A few drops of water were let fall into a basket, formed of a network of platinum wires, heated red hot. The water did not pass through the meshes, even when the basket was rapidly rotated. But when the metal was sufficiently cooled, the water immediately ran through in a shower of small drops, or was quickly dissipated in vapor. It would also seem, that vapors, like liquids, are repelled from the heated surface, for Boutigny found, that a hot silver dish was not attacked by nitric acid, or one of copper by sulphuric acid or ammonia. The latter substance had no action upon either iron or zinc at a high temperature. The suspension of chemical affinity under certain conditions of high temperature, is a fact of great interest in the physics of the globe.

667. **The causes which produce the spheroidal form** in liquids are at least four.

1st.—*The repulsive force of heat* exerted between the hot surface and the liquid, and which is more intense as the temperature rises.

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666. Why does not a spheroid wet the hot surface? What is the evidence of repulsion? How is it shown by experiment? How is it with vapors? 667. What is the first cause named as producing this state?

2d.—*The temperature of the plate* is so high, that the water in momentary contact with it, is converted into vapor, upon which the spheroid rests as upon an elastic cushion.

3d.—*The vapor is a poor conductor of heat*, and thus prevents the conduction of heat from the metal to the globule. Another cause which prevents the liquid from becoming highly heated is, that the rays of heat from the metal are completely reflected from the surface of the liquid. This is shown by the fact, that if the water be colored by lampblack, heat is absorbed, and the evaporation is much more rapid.

4th.—*Evaporation from the surface of the metal* carries off the heat as it is absorbed, and thus prevents the liquid from entering into ebullition. The form of the oblate spheroid, which the liquid assumes, is the combined result of the cohesion of the particles to each other and the action of gravity upon the mass.

668. **Freezing water and mercury in red hot crucibles.**—The remarkable phenomena of freezing water and even mercury in red hot crucibles, are striking examples of the production of the spheroidal state of liquids.

Boutigny placed a portion of liquid sulphurous acid in a red hot vessel. It assumed the spheroidal state immediately, at a temperature below that of its ebullition, that is, below 14° F. A little water placed in the spheroid becomes therefore cooled below (32°) its freezing point, and is converted into ice.

Faraday placed in a heated crucible a mixture of solid carbonic acid and ether, which immediately assumed the spheroidal state. Into it was plunged a metal spoon containing mercury; almost immediately the mercury was frozen into a solid mass. The temperature in this case was probably as low as —148°F.

669. **Connection of certain phenomena with the spheroidal state.** On the principle explained, the hand may be bathed in a vase of molten iron, or passed through a stream of melted copper unharmed, or one may stir fused glass under water without danger. In all similar cases, if the temperature be sufficiently high, the moisture of the hand assumes the spheroidal state, and does not allow of contact with the heated mass. If however the hand is drawn rapidly through the melted metal, contact is mechanically pro-

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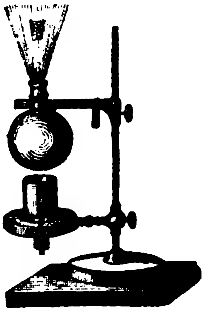
What the 2d? What is the 3d? What is the 4th? What determines the form of the spheroid? 668. How are water and mercury frozen in a red hot crucible? Explain the cause. 669. What singular facts are explained by the spheroidal state? Why is injury not suffered in these exposures?

duced, and injury follows this rashness. The finger, moistened with ether, may be, for the same reason, plunged into boiling water without injury.

670. **Explosions produced by the spheroidal state.**—The experiment illustrated by fig. 364, may be modified to illustrate explosions, and some other interesting facts consequent on the spheroidal state.

A copper bottle, fig. 365, is heated as hot as possible over a double current lamp, and in this state a few grammes of pure water are introduced by a pipette. The water at once assumes the spheroidal condition, and has a temperature (as may be ascertained by a thermometer) below that of its ebullition. If the neck of the bottle is now tightly closed by a good cork, the evaporation is so slight, that the pressure of the vapor within is not immediately sufficient to drive out the cork. If however the lamp is withdrawn, the metal will soon cool sufficiently to allow contact of the water with it. There will then be so sudden an evolution of a large volume of vapor as to drive the cork from the bottle with a loud explosion.

365



671. **Steam boiler explosions** may sometimes be explained by a knowledge of the principles here elucidated. Thus, whenever from any cause a deficiency of water occurs in a boiler, as when the pumps fail of a supply, or when by careening a part of the flues are laid bare while the fire is undiminished, a part of the boiler may become heated even to redness. Water coming in contact with such over-heated surfaces, would first assume the spheroidal state, and almost at the next instant burst into a volume of vapor so suddenly as to rend the boiler with frightful violence. Numerous accidents are on record where the explosion has been so sudden as not to expel the mercury from the open gauges.—The fact that explosions on our American rivers have occurred most frequently just at or after starting from a landing, is explicable on the view here presented; the vessel, while landing and receiving freight, being careened so as to render the exposure of some part of the flues possible.

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670. How may this condition explain certain explosions? Illustrate it from fig. 365. 671. What may be said of steam-boiler explosions?

672. **Applications** and effects of the spheroidal state of liquids, are not unfrequent in common life and in manufactures.

The most common example of the spheroidal state is that of a drop of water on a heated stove, which moves around in a spheroidal mass, slowly evaporating. The laundress determines whether her flat-irons are heated sufficiently for her purpose by touching the surface with a drop of saliva on the finger. If it bounds off, the iron is judged to be heated to a proper temperature. In the manufacture of window-glass, constant application is made of the principles here explained. The masses of glass are first formed into a rude hollow cylinder by blowing them in wooden moulds. In order to prevent the charring of mould, its interior is moistened with water, which, assuming the spheroidal state, protects the wood while it does not injuriously cool the glass.

Saline solutions are more efficacious for tempering steel than pure water. Now as the point of ebullition of saline solutions is higher than that of pure water, contact between the liquid and the metal is produced sooner, and thus the steel is cooled more quickly, and the temper is better.

Melted metals, like iron or copper, allowed to fall into water, do not throw the water into violent ebullition, as might be supposed, but pass in a brilliant stream to the bottom of the vessel, the water in contact with the metal assuming the spheroidal state.

THE STEAM ENGINE.

673. **Historical.**—The principles involved in the construction and theory of the steam engine, have already been sufficiently discussed. A few words must suffice respecting their practical applications in the discovery and perfecting of this remarkable machine.

For the first rudiments of our knowledge of steam as a motor, we must go back, as upon many other so-called modern inventions, to Egypt, where, 130 years B. C., Hero, or Heiro, describes in his '*Spiritalia Seu Pneumatica*,' among many other curious contrivances, (377,) what he calls the *eolopile*.

674. **The eolopile** is a metallic vessel, globular, or boiler-shaped, containing water, and provided at top with two horizontal jet pipes, bent into the form of an *S*.

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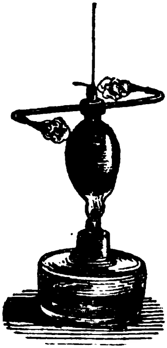
672. Give a familiar example of the spheroidal state. In what processes of the arts is it seen? 673. Where do we find the earliest knowledge of steam as a motor? 674. Describe Hero's eolopile. What is this in fact? What other form has it?

This apparatus, fig. 366, is suspended over a flame, and being free to move, when the water boils, the steam rushing out, strikes against the atmosphere, and the recoil drives the apparatus around with great rapidity. This is in fact a direct action rotary steam engine, and undoubtedly the earliest mechanical result achieved by steam power. It has often been re-invented, in numberless forms, in modern times. In another form the eolopile is made to blow by its jet the flame of a lamp, and in this case the boiler is fixed and filled with alcohol in place of water, the jet descending through the flame of the lamp as in the apparatus seen in fig. 362. Hero describes also other devices where steam was the moving power.

366



675. **First steamboat.**—Blasco de Garay, a sea-captain of Barcelona, in Spain, in 1543, moved a vessel of 200 tons burthen three miles an hour by paddles propelled probably by steam, as the moving force came, it was said, from a boiler containing water, and liable to burst.

This experiment was made on the 17th day of June, 1543, in presence of Commissioners appointed by the King, Chas. V., whose report secured the favor of the crown to the projector. But what is unaccountable, nothing more ever came from this singular success. De Garay probably employed Hero's eolopile on a large scale, as Hero's work above named was about that time translated into several languages and generally diffused.

676. **Baptista Porta, and Solomon De Caus,** the first at Naples in 1601, and the second a Frenchman in 1615, both re-describe the eolopile of Hero, but in a very inferior form to the original, and without adding anything to what was before known.

Giovanni Branca of Rome, in 1629, also describes a contrivance for obtaining a rotary motion from steam blowing against the paddles of a wheel, shaped like an ordinary water wheel. This impotent form of steam apparatus has been again re-described in much more modern times.

677. **Otto V. Guerick,** the inventor of the air-pump, about 1650, first conceived and executed the idea of using the pressure of the atmosphere as a moving force, for raising water or lifting weights. His rude apparatus did not involve the use of steam,

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675. What did Blasco de Garay accomplish? When and how was this? 676. What is said of B. Porta and S. de Caus? 677. What did V. Guerick accomplish and when?

but he produced a vacuum by the air-pump, which then drew up by a rope and pulley a platform with weights. The production of a vacuum by the condensation of steam remained still to be discovered.

678. **The Marquis of Worcester**, in 1663, in his 'Century of inventions,' describes what he calls 'a water commanding engine, an admirable and most forcible way to drive up water by fire.'

Unfortunately no figure of Worcester's engine exists, but his description of it leaves no doubt that he used steam to create a vacuum into which water afterwards rose to be again expelled by fresh steam, as was accomplished later with more success in Savary's engine.

679. **Savary's engine.**—In 1698, Capt. Thos. Savary obtained a patent 'for raising water and occasioning motions to all kinds of mill work by the impellent force of fire.' His apparatus can hardly be called an engine, or machine, since it has no moving parts except the valves turned by hand.

367

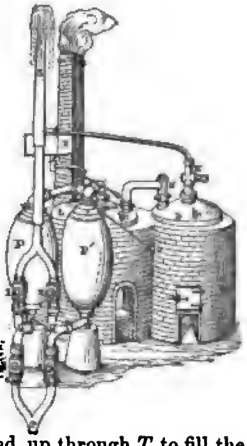

Fig. 367 is Savary's engine. Two boilers, *L* and *D*, are connected together by the pipe, *H*. Two 'condensers,' *P* and *P'*, are connected with the larger boiler, *L*, by pipes entering at top of both, and capable of being alternately shut off from the boiler by a valve, moved by the lever *Z*. By two branch pipes beneath the condensers, communication is established at pleasure, by the aid of the cocks 1, 2, 3, 4, alternately with the well by *T*, and the open air by the outlet pipe *S*. The boiler, *L*, being in action, the condenser, *P*, for example, was filled with steam, the cocks 1 and 3 being closed. By moving *Z*, the condenser, *P'*, was next filled with steam also, cocks 2 and 4 being closed, and at the same instant cock 3 being opened, the water rushed up through *T*, to fill the vacuum occasioned by the condensation of the steam in *P*. The lever, *Z*, was then moved to close *P'* and open *T* again to the boiler. Cock 4 now admitted cold water to *P'* and cock 1 being opened, the direct pressure of the steam from the boiler forced the water out of *P*,

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678. What was the Marquis of Worcester's invention? 679. What was Savary's patent for, and when? Describe his apparatus, fig. 367, and how the discharge was made continuous.

in a stream through the discharge pipe, *S*. The water in *P'* was also discharged in the same manner, and so on, alternately, each condenser was filled with cold water, and again discharged, maintaining a continuous stream of water from *S*. To supply the waste of water in the boiler, *L*, the contents of the smaller boiler, *D*, were from time to time forced by superior steam pressure into *L*, through the pipe *H*, (provided with a valve for that purpose,) reaching near the bottom of *D*, whose capacity was such as to fill *L* to a suitable height. The boiler, *D*, was then re-filled through the pipe, *E*, from the supply box, *X*, attached to the discharge pipe.

All the details of Savary's contrivance show a nice adjustment of means to the end to be accomplished, and evince much ingenuity and sound judgment.

680. **Papin's steam cylinder, Newcomen's engine.**—Denys Papin, (Prof. of Mathematics at Marburg,) whose name is connected with the high-steam digester, fig. 364, suggested in 1690 the use of steam to produce a vacuum in Otto and Guerick's cylinder (677) in lieu of the air-pump before used.

For this purpose he constructed the cylinder of sheet iron, and built a fire beneath its bottom, to boil a portion of water there placed. When the cylinder was filled with steam, the piston before held up by a latch, descended as the steam was condensed. No practical result followed this clumsy contrivance, on which Papin's countrymen rest his claims to be considered as the inventor of the steam engine.

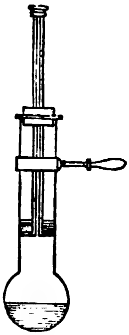
THOS. NEWCOMEN, in 1710, first put in practice the use of a cylinder and piston in the steam engine, in which the steam was alternately admitted and again condensed by a stream of cold water. This engine, like all following it, up to Watts' remarkable improvements, operated against the pressure of the atmosphere, and was effectual in only one direction, *i. e.*, was a single acting engine.

681. **The atmospheric engine** is well illustrated by the apparatus shown in fig. 368, which was contrived by Dr. Wollaston, to show the nature of Papin's cylinder.

A glass, or metallic tube, with a bulb to hold water, is fitted with a piston. This piston-rod is hollow, and closed by a screw at *a*.

What is said of this invention? 680. Who suggested the use of steam to form a vacuum, and when? What followed this suggestion? Who first employed a cylinder and piston with success? 681. How is the atmospheric engine illustrated by fig. 368? What great source of loss existed in all atmospheric engines?

368



This screw is loosened to admit the escape of the air, and the water is boiled over a lamp: as soon as the steam issues freely from the open end of the rod, the screw is tightened, and the pressure of the steam then raises the piston to the top of the tube, the experimenter withdraws it from the lamp, the steam is condensed, and the air pressing on the top of the piston forces it down again; when the operation may be repeated by again bringing it over the lamp.

In all the early steam engines, the steam was condensed within the cylinder, either by water applied externally, or by a jet of water thrown directly into the cylinder. It is very obvious, that a great loss of fuel and time was thus involved in bringing up the cylinder again to 212°, before a second stroke could be made

Newcomen and Smeaton constructed very large engines, however, on this principle, and applied their power directly to the pumping of mines. Although Smeaton introduced an improved class of mechanical work and many improvements in minor details, and better boilers, he succeeded only in raising the average duty of steam engines from about five and a half millions of pounds, raised one foot by a bushel of coals (80 lbs.) burned, to about nine and a half millions, in his best engines. A good pumping engine now raises from ninety to one hundred and thirty millions of pounds for every bushel of coals burned!

682. **Watt's improvements in the steam engine.**—The steam engine as it was left by Smeaton was, as we have seen, only a steam pump, confined to the single function of raising water, and incapable of general use, as well from its imperfections as from the enormous cost of fuel it required.—Watt, in 1763, was a maker of philosophical instruments at Glasgow, and had occasion to repair a model of the Newcomen engine. The study of this machine and its defects, led Watt to construct a new model, in which the steam was condensed in a separate vessel, in connection with which he subsequently found it advantageous to use an air-pump—to aid in keeping the vacuum good, as it was otherwise vitiated by atmospheric air leaking in, and coming from the water of the boiler. These ideas were matured and realized by

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What is farther said Newcomen and Smeaton? What was the duty or power of their best machines? 682. How did Watt find the steam engine? What led him to improve it? In what did his improvements chiefly consist?

1765, and in 1769 he took out his patent, in which all the essential features of our modern steam engines are included. In connection first with Mr. Roebuck, of Carron Iron-works, and subsequently with Mr. Boulton, of Soho, he put his ideas in practice, and by reserving to the patentees one-third part of the saving of fuel effected by his improvements, his genius was rewarded by the accumulation of a princely fortune.

Watt's invention of low-pressure condensing engines stands without a parallel in the history of science for the perfect realization of all the conditions of the problems to be solved—the perfect mastery of the laws of nature and the use of matter, by which they were accomplished, and the thorough exhaustion of the subject even in its minutest details, so that to this day we have no improvements in this machine involving a single principle unknown to Watt. In the beauty and perfectness of mechanical work, in size of parts, and the strength of boilers, we have machines greatly superior to any Watt ever saw, but it was his genius that rendered those perfections possible, and supplied the very power by which they have been worked out.

683. **The low pressure or condensing engine.**—The low pressure engine is employed in all situations where economy of fuel and the best mechanical effect from it are the ruling considerations, and where lightness and simplicity of construction is unimportant. This machine now remains almost exactly as Watt left it. Owing to the nearly perfect vacuum obtained in it by the condenser and air-pump, a much less boiler pressure of steam is required to produce a given mechanical result, *e. g.*; if the vacuum is equal to fourteen lbs. atmospheric pressure, then a steam pressure of six lbs. would give an efficient moving force of twenty lbs. to the machine. Hence the propriety of the term 'low pressure' engine; but in practice it is found advantageous to use higher pressures in the condensing engines than Watt ever contemplated.

Fig. 369 is a section of the cylinder, *A*, condenser, *e*, air-pump, hot and cold well, and a view of the most important attached parts of a modern condensing engine. The cylinder, *A*, is seen receiving steam at top through the throttle-valve, *a*, driving down the piston, *B*, with its rod, *C*. A stream of cold water injected into the condenser, *e*, has completely condensed all the residual steam of the for-

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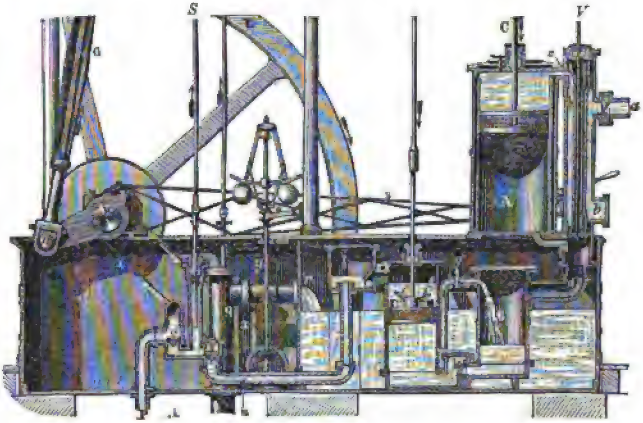
Give the date of his discoveries and patent. What is further said of his invention? 683. Why is this called a *low pressure* engine? Why a *condensing* engine? When is it chiefly employed? Describe fig. 369, and the functions of the several parts.

mer stroke which has found its way from *A* by the eduction pipe, *d*, so that the piston, *B*, is descending into a nearly perfect vacuum, (623.) The hot water of this condensation is constantly drawn off

369



through the valve, *k*, by the air-pump whose valves, *i i*, rise to allow its flow into the hot well, *l*, whence it finds its way, solicited by the plunger pump, *S*, to the boilers by the pipe, *P*, and its valves, *o o*. The cold water pump, *q*, supplies a steady stream of cold water by the spout, *r*, to the cold well. By the time the piston, *B*, has reached its lowest point of descent, the valve rod, *V*, and eccentric bar, *S*, have moved so as to open the lower steam ports and reverse the direction of the piston, when the steam above, *B*, is in its turn taken into the condenser, *e*, by the appropriate channels, and removed as already explained for the downward stroke. The piston rod, *C*, and valve and pump rods, are connnected above with the great working-beam, whose further extremity conveys the power of the engine by the pitman, *G*, through the crank pin, *H*, to the main shaft, *K*, on which is the fly-wheel, *L*, to give steadiness of motion to the whole apparatus. The arrows show the motion of these parts as the piston descends. The governor, *z*, controls the throttle valve, *a*, by connections not shown in this drawing.

684. **The high pressure engine.**—In this machine, the escape steam is driven out against the pressure of the atmosphere, and no attempt is made to utilize its capacity to form a vacuum, con-

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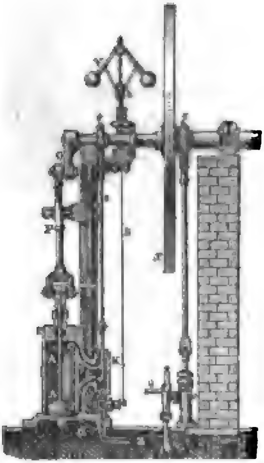
684. How does the high pressure engine act? What beside steam could be used in it, and why?

sequently this form of apparatus could be used as well with condensed air, or any other elastic fluid, as with steam, if there was any other that could compete in economy with it. The lightness, simplicity, and low cost of the high pressure engine, makes it available in spite of its uneconomical use of steam, in many situations where a condensing engine would be unavailable.

370



The steam arrives by the pipe, *Z*, fig. 370, to the steam chest, *R*, and is admitted alternately by the ports *e d*, to the top and bottom of the cylinder, *A A*, as the valve rod, *S*, actuated by the eccentric, *f*, on the main shaft, opens and shuts the ports by the slide valve in *K*. The escape steam makes its exit through *g*, to the atmosphere. The pitman, *P*, conveys the motion of the piston, *C*, to the crank, *Q*, and the main shaft, on which is the large fly-wheel, *x*, to accumulate momentum. The flow of steam is regulated by the governor, *V*, whose balls fly out with the centrifugal force of a more rapid motion, and by the rod, *h*, *b*, close more or less the throttle valve, seen in section in *Z*; the pump, *o o*, supplies water to the boiler, and is moved by the rod and eccentric, *g*, on the main shaft.

Cut off.—The supply of steam both to the high and low pressure engine is further regulated by a contrivance called the 'cut off,' which may be set to cut off the flow of steam entirely, or at any portion of the stroke, as one-half, or one-third. The expansion of the steam then completes the work, and great economy of fuel is found to follow its use.

685. **Steam boilers.**—The form of steam boilers varies very much with the purpose to which they are to be applied. On land, large boilers may be safely used, which would be wholly valueless at sea, or on a locomotive engine.

Plate-iron strongly riveted and braced, is the material combining the greatest economy and strength. Copper can be used only when the fuel contains no sulphur, and is the best material to resist corrosive

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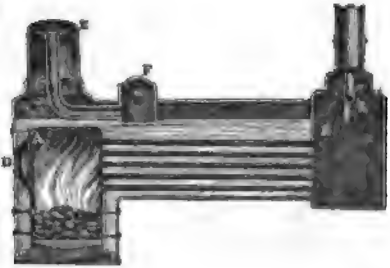
Describe the figure 370. What is the '*cut-off*,' and how does it act? 685. What is said of steam boilers?

agents. Simple cylindrical boilers, laid horizontally, with a fire-flue under the whole lower surface, are commonly used for high pressures. When these are made large enough to receive the furnaces within and distribute the heat in interior flues, they are called Cornish boilers. When their construction is still further modified, with reference to the greatest possible increase of fire surface, they are called locomotive boilers, as in the annexed figure, 371; being the common locomotive boiler seen in section. *D*, is the feed-door, for fuel to the furnace or fire box, *A*, which communicates by numerous small horizontal tubes, entirely surrounded by water, with the base of the chimney, *B*, into which the blast of exhaust steam from the engine is driven at *K*. *E*, is the steam chamber, where a trumpet tube in the dome conveys the dry steam on its way to the cylinder through *F*. Steam boilers are supplied with hot water by a force pump, and gauge cocks indicate the water level.

371



686. **Mechanical power of steam.—Horse power.**—As steam engines were originally employed to take the place of horses in raising water it was natural to estimate their power by the number of animals they replaced. The value of any force is correctly stated as the number of pounds raised one foot high in a given time, (foot-pounds.) As the use of steam became general, the term *horse-power* was retained, but its use was restricted by Watt to mean 33,000 lbs. raised one foot per minute, or nearly 2,000,000 lbs. raised one foot per hour.

As one cubic inch of water converted into steam yields in round numbers 1,700 cubic inches of vapor, its mechanical effect at atmospheric pressures, is equivalent to raising 15 lbs. 1,700 inches, (or 142 feet,) in a tube of one inch area. But 15 lbs. raised 142 feet, is the same thing as 142 times 15 lbs. raised one foot, or 2,130 lbs., or nearly a gross ton. The total mechanical force developed by changing one cubic inch of water into 1,700 cubic inches of steam is therefore nearly one ton. Only 60 or 70 parts of this power are however regarded as ac-

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Describe figure 371. 686. What is the origin and meaning of the term horse power? How did Watt limit it? How is the mechanical power of steam illustrated from a cubic inch of water?

tually available in use, deducting friction and loss from other causes. Therefore the evaporation of a cubic foot of water in an hour, subject to this deduction, will give the full force of about 1,000 cubic inches of water converted into steam, as the expression of one-horse power, (viz. 33,000 × 60 m. = 1,980,000 lbs.,) or nearly 2,000,000 lbs. raised one foot. This is a somewhat rough approximation, but it gives constants easily remembered and sufficiently near the truth.

A boiler of one-hundred horse power means, then, a boiler capable of evaporating 100 cubic feet of water per hour.

In practice it is common to allow in large land engines for every horse power, one square foot of fire bars in the boiler, three cubic feet of furnace room, ten cubic feet of water in the boiler, and ten cubic feet of steam chamber. In locomotives and steamships these proportions vary very much.

687. **Evaporating power and value of fuel.**—In England, engineers estimate ten pounds of bituminous coal for every cubic foot of water (*i. e.* every horse power) to be evaporated. In carefully constructed boilers, however, this effect is produced by seven or eight pounds of coal.—In the Cornish boilers, where a very large evaporating surface is allowed, five pounds of coal only, and sometimes less, are used per horse power. In the U. S., anthracite coal averages ten pounds of water evaporated, for every pound of coal burned. This would give 6·25 lbs. of anthracite for each cubic foot of water evaporated. A well regulated current of vapor conducted over the flame of bituminous coal by Dr. Fyfe, raised the evaporative effect produced 37 per cent. above what was obtained from the unassisted coal. This increase is due to the decomposition of the steam by the hot fuel, and the consequent effect of the pure oxygen on the carbon. Well seasoned wood, (beech or oak,) still containing about 20 per cent. of water, and well dried peat, have about equal evaporating power, and are only about two-fifths as effective as an equal weight of ordinary bituminous coal.

Welter has observed that those quantities of a combustible body which require an equal amount of oxygen for combustion, evolve

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What proportion of the whole power is regarded as available? What relation has a cubic foot of water to a horse power? What is meant by a boiler of one hundred horse power? What proportions of fire bars, furnace room, and water and steam room are allowed in land boilers? 687. What is said of the evaporating power of coals? What is the case with American anthracite? What is the effect of of vapor of water on a coal of fire? What is the comparative value of wood, peat and coal? What was Welter's observation?

also equal quantities of heat: although later researches show this conclusion not to be strictly true, it is supported by many facts. In all cases of combustion, the action is reciprocal, the oxygen is burned in the fuel as truly as the fuel by the oxygen, and therefore the same amount of heat is generated by a given amount of oxygen, whether in converting carbon into carbonic acid, or hydrogen into water. To burn one part of carbon, requires 2·66 parts of oxygen, ($CO_2 = 16 \div 6 = 2{\cdot}66$,) and to burn one part of hydrogen, requires 8 parts of oxygen. It has been proved experimentally, (by Rumford,) that 78 parts of water are raised from 32° to 212° by burning one part of carbon, while one part of hydrogen so burned will raise 236·4 parts of water through the same degrees. It therefore follows that one part of oxygen, burning carbon, will heat $78 \div 2{\cdot}66 = 29{\cdot}25$ parts of water from 32° to 212°; and also that the same quantity of oxygen, in burning hydrogen, will heat $236{\cdot}4 \div 8 = 29{\cdot}56$ parts of water through the same degrees. The heating effect of oxygen may therefore be assumed to be 30, or in units of heating power 3,000.

If the heating effect of pure carbon is taken at unity, the relative heating effects of the other combustibles will range as follows, for equal weights: hydrogen, 3; vegetable oil, 1·15—1·22; ether, 1·02; carbon, 1; wood charcoal, 0·96; alcohol, 0·86; good coal, 0·77; dry wood, 0·46; wood, (with 20 per cent. water,) 0·35; peat, 0·33—0·38. (Knapp.)

PROF. W. R. JOHNSON ('experiments on coals') and others, argue as the result of experiment, that the total amount of carbon in a fuel is the measure of its practical evaporative power. His results very nearly sustain this view. He found also that about 86 per cent. of the total heating power were expended in evaporating water, and about 14 per cent. were lost in the products of combustion. Of the total heating power, by calculation, about 26 per cent. were lost in practice—as deduced from the experimental effects stated in his tables.

VENTILATION AND WARMING.

688. **Currents in air and gases** depend upon principles which have already been fully explained—but the subjects of ventilation and artificial heating are of such great importance in daily life, that they demand a brief space for separate consideration.

Illustrate this. What is the heating power of oxygen? What is the relative heating power of hydrogen, &c., carbon being unity? What did Johnson assert of the heating power of a fuel? State his results. 688. How do currents arise in gases?

Currents arise in air from differences of temperature and variations of pressure. The perfect freedom of movement in air, renders its fluctuations from these causes incessant. If the air was visible, every candle, gas-light, stove, furnace-flue and human body, would be seen to be the centre of an ascending column of heated air, whose place was constantly supplied by other and colder particles.

On the law of the equilibrium of fluids, the ascending currents must induce others, descending and horizontal, and thus a circulatory motion is imparted, even by a single lighted candle, to the whole gaseous contents of a quiet apartment. These currents are made visible whenever the candle smokes. If the door of a heated apartment stands ajar, and a candle is held near the top crack, the warm air of the room is seen to suck outwards, carrying the flame with it, and a corresponding cold current flows in at the bottom—while a point will be found, midway its height, where the candle flame is undisturbed. So a window partly open will occasion a draught of cool air, blowing in at the bottom of the opening, and a compensating warm current will escape outwards, above.

This constant interchange of motion in unequally heated masses of air, while it soon poisons the confined atmosphere of a close apartment where many persons with or without lights are assembled, also supplies the easy means of curing one of the greatest evils of civilized communities.

689. **Draught in chimneys.**—Chimneys draw because the products of combustion discharged into them are specifically lighter than the outer air. The column of heated air rises with a velocity proportionate to the excess of weight in a column of the outer air of the same area and height. The laws of falling bodies (156) apply to this case in every particular.

Suppose, for example, a chimney is 18 feet high, and the gases in it are heated to 100° F., the outer air being 70°. The contained column would therefore (547) expand $\frac{30}{490}$ or about $\frac{1}{18}$th of its original bulk at 70°. A column of 19 feet of such air would therefore be required to counterbalance one of 18 feet high in the external air at 70°, and of the same area. (252.) The heated air will therefore rise, (for the same reason that a balloon rises,) with a velocity equal to that acquired by a body falling through one foot, *i.e.* a space equal to the difference in height of the two columns—of *equal weight*. The laws of gravity

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What follows the ascending current? Illustrate this by the open door. 689. Why do chimneys draw? Why does the heated column rise?

therefore supply the means of calculating the theoretical velocity of the ascending column, and of course that, with the area of the cross section of the flue will determine the quantity of air passing through the chimney in a given time. But the friction of the air against the sides of the flue, and the varying density of the products of combustion compared to air, diminish the theoretical velocity, and it is usual to allow a deduction of one-fourth for these causes. The following rule will be found to give a sufficiently exact expression of the velocity of air in chimneys and ventilating flues.

Multiply the square root of the difference in height of the two columns of air (deduced as above) expressed in decimals of a foot, by eight; deduct one-fourth, and the product of the remainder, multiplied by sixty, will give the velocity of efflux per minute; and the area of the flue in feet, or decimals of a foot, multiplied by the velocity, will give the number of cubic feet discharged per minute.—(Hood.)

This rule, in the case supposed, would be $8\cdot\ \sqrt{1} = \cdot 1 - \frac{1}{4} = \cdot 6 \times 60 = 360$ cubic feet of gases discharged per minute, by a flue eighteen feet high and one foot area, whose temperature is 30° above the outer air.

Chimneys, in the sense we mean, were not known to the ancients. Holes in the roof and windows allowed the escape of smoke from the kitchens of the luxurious Romans. But the mild climate of the mediterranean shores did not require much attention to means of artificial warmth. In the houses of ancient Herculaneum and Pompeii, exposed in modern times, there are no chimneys. But even in England and France, where fires in winter are necessary, chimneys were first introduced only in the middle of the 14th century. The curfew bell (*couvre feu,* fire cover,) was needed as a precaution against the danger of fires, without chimneys.

690. **Reversed draughts and smoky chimneys,** occur, 1st, when the flue or fire place is badly constructed; 2d, when two flues open into one apartment, or two connecting apartments, and there is a fire in only one flue; 3d, when a powerful fire exists in one part of the house, as the kitchen for instance, without an adequate supply of air from without, it will draw the needed supply through the smaller flues in all parts of the house, reversing the draught in them; 4th, when (as in many old houses)

By what law? Give an example. What is the rule for calculating the draughts of chimneys? Apply it to the example. What is said of the history of chimneys? 690. What are causes of a reversed draught and smoky chimneys?

the flue is so large that cold currents may descend in the angles while a heated one ascends the axis; 5th, when a neighboring higher house or eminence directs, in certain states of the wind, a cold current down the flue.

The remedy for reversed draughts is best found in one commanding central stack, into which all the minor flues discharge, while exhausting cowls, like fig. 366, are the best cure of smoky chimneys.

691. **Products of respiration and combustion, and necessity for ventilation.**—By contact with the lungs, and with burning fuel, the air is contaminated chiefly with carbonic acid, water, effete nitrogen, oxyd of carbon, and animal odors. Every full grown individual consumes in every minute of quiet respiration, 350 to 500 cubic inches of air. About 14 ounces of carbon are burned by the air out of the body of a man in twenty-four hours, and all this is returned in the form of carbonic acid to the air.

Such air cannot be breathed again without danger. Mixed with the surrounding air, it contaminates that also. Headache, languor, uneasy respiration, nausea, faintness and syncope, are results which always follow from breathing air contaminated with these poisonous exhalations, even in very moderate quantity. Even two per cent. of carbonic acid driven from respiration or combustion, may produce all the symptoms above named. The full chemical and physiological evidence upon this important subject cannot be here given, but the evils arising from the slow and insidious effects of the poison of bad ventilation, can hardly be over-estimated.—In ordinary combustion, especially with slow fires and an imperfect supply of air, carbonic oxyd is also produced, and is one of the gases most likely to leak from hot-air furnaces when the joints are not tight. It is abundantly more poisonous than carbonic acid, or those gases of sulphur, whose presence is at once declared by their odor.

692. **The quantity of vapor given off by the body** in sensible and insensible perspiration and by the lungs, is very considerable, being not less than ten or twelve grains each minute, or about three pounds per day, which, with the quantity of carbonic acid expired, makes about three and a third pounds, beside other excrementitious matter given off in twenty-four hours.

How are they remedied? 691. What quantity of air does a man consume? What does he throw off? What effect have these on the system? 692. What amount of vapor does a man exhale?

If the air of a crowded apartment is conducted through water, so much animal matter is collected in the water as to occasion a speedy putrefactive fermentation, with a disgusting odor, and the blast of air escaping at the upper ventilator of a crowded assembly room, is so oppressive as to produce immediately the most distressing symptoms. While we instinctively shun all contact with unclean persons, and what we call dirt, even refusing a cup that has pressed the lips of another, and esteem all water not transparent as foul, it is marvellous with what thoughtlessness we resort to crowded and ill-ventilated public places, and drink in the subtle poison exhaled from the lungs, skin and clothing of every individual in the assembly. Especially when we remember that while the digestive apparatus can select and assimilate nutriment from food of questionable quality, the lungs can discharge their duty to the blood only by a full supply of pure air. If the transparency of air was troubled by the exhalations of the lungs as water is by the washings of the body, no argument would be needed to secure attention to the importance of ventilation; and yet it is quite true that the bodily health suffers more from inhaling effete air than it could from drinking the wash alluded to.

693. **The quantity of air required for good ventilation** is very variously stated by different authorities. Enough fresh air must be supplied, obviously, to replace all that is contaminated by the lungs, the body and sources of illumination. But to determine exactly how much these several sources of deterioration demand, is not so easy. The amount of air needed to remove the products of respiration is very much less than is required to absorb the vapor of water given off from the lungs and the skin. The quantity of vapor the air can take up, will depend on its dew point and temperature. Hood estimates three and one-quarter cubic feet of air per minute for each individual in winter, with an external temperature of 20° or 25°, and a quarter of a cubic foot per minute to supply the waste from the lungs, making three and a half cubic feet per minute, or two hundred and ten cubic feet per hour in winter, and five hundred in summer. Peclet estimates it at two hundred and twelve cubic feet per hour. Dr. Reid estimates the quantity much higher, even as high as thirty cubic feet per minute per individual. Brenan puts it at 10·25 cubic feet.

694. **Products of gas illumination.**—Every cubic foot of gas, of average quality, requires the oxygen of about twenty cubic

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What is inferred of the importance of ventilation? What reflection is drawn from this fact? 693. How is the quantity of air for ventilation estimated? Name the different opinions.

feet of air (viz. 4·25 cubic feet oxygen) to burn it, and produces rather over a cubic foot of carbonic acid, still more water, and if the gas is impure, sulphurous acid and compounds of ammonia will be added, which, dissolving in the watery vapor, condense upon and corrode furniture, books, metallic articles, &c. Every pound of coal gas burned produces 2·7 lbs. of water, and 2·56 lbs. of carbonic acid, and as a cubic foot of coal gas weighs almost 290 grains, twenty cubic feet will weigh a pound, a quantity which four common fish-tail burners consume in an hour. The capacity of air for moisture at 68° is 7·31 grs. It would, therefore, require over two thousand feet of air at zero, to retain the water from twenty feet of gas, and over double that quantity at the temperature assumed, not to name the amount required to dilute the carbonic acid and free nitrogen produced.

It is needless to add, that the ventilation of gas burners is an important matter. Fortunately, a gas chandelier affords one of the best means of producing an upward current in an assembly room. Candles and oil consume more air, and of course produce more effete products for an equal amount of light than gas.

695. **The actual ventilation of buildings** is a practical problem, to be wrought out in each case, with careful regard to the principles and facts just stated. The supply of air required may be obtained in two ways. 1st, by the ascending column of heated air in a shaft, drawing after it the effete air to be removed, and supplying its place by fresh air, warmed in its progress to the apartments. This is called *thermal* ventilation; or, 2d, mechanical force may be employed, by means of revolving fan-wheels driven by a steam-engine, or otherwise, forcing the air through the apartments to be warmed and ventilated. This is called *mechanical ventilation.*

By the first method, Dr. Ried ventilated the House of Commons in England. By the second, Mr. Rice ventilated the House of Lords with a fan-wheel, over thirty feet in diameter.

696. **Stone's ventilating shaft.**—An excellent combination of the thermal ventilation, with the plan of hot-air furnaces, so generally used in the U. S., has been devised by S. M. STONE, Architect, which has been found efficient in the New Haven City

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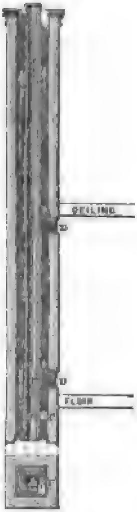
694. What are the products of gas illumination? What quantity of water and carbonic acid form a pound of coal gas? How much air is required to remove these? 695. What methods of ventilation are named? 696. Describe Stone's ventilating shaft?

Prison, the State Reform School, and other similar buildings. Fig. 372 shows a plan and section of this system.

A ventilating shaft of brick, *C*, rises in the centre of the house, through the axis of which passes a cast-iron smoke flue, *A*, carrying off the waste products of the furnace. The radiant heat of this iron flue heats the air in the shaft, *B*. Openings, *D* and *D*, are pierced from the various apartments into this shaft, and allow the air of the rooms free opportunity of escape; solicited by the powerful ascending draught of the vertical shaft. Distant apartments are connected with the shaft by horizontal pipes of wood or tin. The openings, *D*, should be covered by wire gauze and fitted with Dr. Arnott's self-acting noiseless valve, which allows the passage of an upward current only. The apartments are supposed to receive their supply of fresh and warm air through hot air flues, ascending in the walls. In summer it would be found needful to establish a current in the shaft by an occasional fire in the furnace, or by a special furnace for that purpose in the top of the house. In cities, the air taken into buildings may be strained through fine wire gauze and spray of water, as was accomplished by Dr. Ried in the House of Commons. By the rule, (689,) the power of such a shaft to discharge air can be calculated.

372



697. **Cold currents produced by ice.—Refrigerators.**—Air in contact with ice acquires, of course, a low temperature, and parts with a large part of its moisture. Thus snow-clad mountains and glaciers naturally send down to the valleys below a current of cold air, flowing like water over the surface, especially at night, when the absence of the sun prevents the accumulation of heat on the earth's surface.

Adroit use has been made of this cold dry current, in the construction of refrigerators for preserving food in warm weather; and the same principle has been applied, in a large scale, to the cooling of large apartments. Figs. 373 and 374, show a section and elevation of Winship's Refrigerator. The ice, *A*, fig. 374, is sustained upon a

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697. How is a cold current produced by ice? How is this availed of in the refrigerator, fig. 372?

shelf in the upper part of the box, surrounded with double charcoal linings. The air enters by the register openings, *C*, and coming in contact with the ice, is cooled, and falls to the bottom, as indicated by the arrows, where it finds its egress at *E*, between hollow walls, and finally escapes at *F*, as in an inverted syphon. In this way a gentle current of about 45° F. is steadily maintained as long as the ice lasts, and being dry, articles of food are preserved sweet and free from mould for a long time. A similar device has been used for large apartments.

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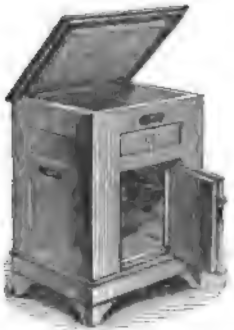

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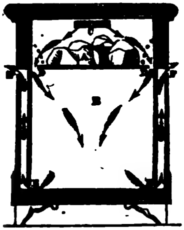

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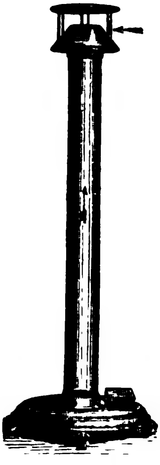

698. **Cowls.—Emerson's ventilators.**—Advantage is taken of the currents in the external air, to aid in establishing ventilation in houses, and draught in chimneys, by the use of ventilating cowls.

These contrivances are often conical, and hung with a vane, to turn against the wind. One of the most generally approved, however, in common use, appears to be the ventilator of Emerson, fig 375, which is simply a cone of metal, surrounding the flue, over whose vent, and a short distance above it, is sustained a disc of metal. If the wind blows from any point, its effect, on striking this conical surface, is to pass upwards and across the open flue, with an increased velocity. The result is to solicit an upward current in the shaft, as shown by the arrow, in the figure.

If it is desired to direct a current of fresh air *into* the shaft, an *injecting ventilator* is used, which is simply the above cone *inverted*, or two or three such, placed one over the other. These are found

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698. What are cowls? Describe Emerson's, fig. 375, and its action?

very efficient in projecting fresh air into the cabins of ships, and other similar situations.

699. **The supply of fresh air** in dwellings is derived in the winter almost exclusively from the cracks and joints of doors, windows and other openings. In all good systems of general warming, this supply is derived from the open air, or a free basement, and is warmed in its progress through the heating apparatus. When it is requisite to introduce cold air into a house, it is important to do so in such a manner as to avoid local and sharp currents; for this purpose, perforated cornices, or openings covered by wire gauze, are provided.—A too rapid current is both inconvenient and costly, from the needless waste of fuel.

In public buildings, the supply is best obtained through a trench, or horizontal tube, opening into a clean area, and protected against powerful winds. The injecting cowl may be advantageously used to cover the opening of such a supply. The distribution of the ascending warm current is best made through a hollow or double floor, perforated with numerous openings, while the spent air is taken off above, as already described.

Warming.

700. **The artificial temperatures** demanded in cold climates are produced, 1st, either by radiant heat solely, as in the common open fire-place, 2d, by convection only, as in hot-air furnaces of every description, in which the air is warmed by its passage through a heating chamber, and then introduced into the apartments to be warmed—or 3d, by radiant heat and convection united, as in stoves, and steam or hot water pipes.

701. **The open fire** contained in a simple brick fire-place, whether coal or wood is burned, warms the air of the room solely by radiant heat. The burning fuel solicits the air of the apartment to be warmed towards the chimney, where, coming in contact with the fire, it parts with a portion of its oxygen to sustain combustion, is intensely heated, and rising, escapes at the flue, with the heated products of combustion. Hence only the heat radiated from the burning fuel and hot walls, is effectual in warming the apartment, while much the largest part of the heat (three-fourths to four-fifths of the whole) escapes up the chimney.

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699. How is the supply of air obtained, and how distributed? 700. How are artificial temperatures produced? Distinguish the three grades? 701. How does the open fire warm? Why is this?

The genial effect and cheerful aspect of an open fire, combined with the efficient means of ventilation it affords, render this old system very popular, when combined with some competent general plan of warming the whole house.

Dr. Franklin improved the common fire-place by introducing iron stoves, of the same general form, and connecting them with the chimney by a circuitous pipe, by which means a much better economical effect was attained. Rumford improved the form of the fire-place very much, and especially with reference to the throat of the chimney and angle of the jambs. He also combined it with a circulation of hot air behind and at the sides of the fire, so as to obtain the effect of a stove.

Stoves of iron, standing in the apartment to be warmed, offer, perhaps, the most economical mode for burning fuel—but when, as is too often the case, they are closed tight, except a very small opening for draft, they are among the vilest contrivances in use for the ruin of the public health. The atmosphere of the room unavoidably becomes over-heated and corrupted by the products of respiration, in the almost universal absence of any mode of ventilation.

702. **Hot air furnaces.**—Large buildings and dwelling houses are frequently warmed by air heated in its passage through a structure in the lower part of the house. One of the simplest forms of apparatus for this purpose is seen in fig. 376, being a sectional view of a hot air furnace, in which the cold air entering at *A*, passes, as indicated by the arrows, through an extended system of iron passages set in brick work and heated by the products of combustion, and the direct action of the fire, *F*. The heated air gains the apartment, *m*, by openings, *B*, in the floor or sides of the wall, while the gases of combustion escape by the flue, *O*. Such an apparatus serves only to illustrate the general principle, and would prove valueless in practice.

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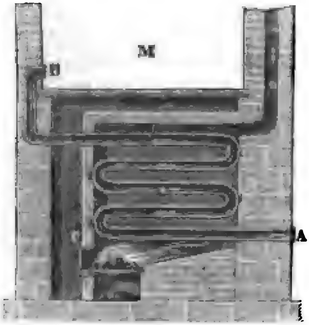

How did Franklin and Rumford improve the common fire-place and chimney? What is said of close stoves? 702. Describe the general principles of the hot-air furnace from fig. 376.

Very numerous forms of hot-air furnaces are in use in the U. S., chiefly for the combustion of anthracite coal. They are essentially alike in principle, but very unlike in construction. All take cool air from without, or from an airy basement, and after heating it in a brick chamber, by contact with surfaces of hot iron surrounding the fire, and conveying away the products of combustion, distribute it by flues in the wall to the several apartments. Fig. 377 presents a sectional view of one of the best hot-air furnaces at present in use. (Chilson's.) The fire of anthracite is contained in a large shallow pot of cast-iron, with soap-stone, or iron staves, and the heated products of combustion are expanded in an extensive system of chambers of cast-iron, all communicating with an annular cast-iron pipe, leading to the chimney. This arrangement affords a very extended radiating surface, with few joints, to allow the escape of noxious gases into the surrounding hot-air chamber. The arrows indicate the direction of the current. In fig. 378 is seen the furnace, surrounded in the brick work, which is hollow. The cold air enters at the bottom and being gently heated by contact with the hot-air surfaces within the chamber, as well as by the radiant heat from the same source, it escapes by the openings, *o o*, to the various apartments. The extended iron surface in this apparatus prevents any part of the furnace from becoming very hot, usually the chief causes of complaint against this mode of heating. Air is materially injured for purposes of respiration by contact with over-heated surfaces, owing to the charring of the particles of dust and dirt always floating in it. The chief objection resting against this and similar modes of heating is the entire absence of ***radiant heat in the apartments***, whose occupants are, so to speak, immersed in a warm air bath, and require, consequently, several degrees more heat, by the thermometer, for comfort, than when radiant heat forms a part of the means of an artificial temperature.

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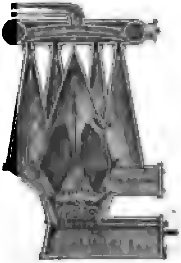

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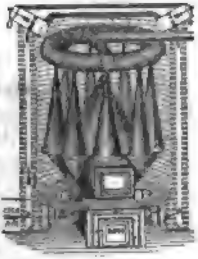

Hot-air furnaces are commended on account of their economy of construction, and ease of management, and when combined with a good system of ventilation, such as is secured by an open fire in one

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What are the anthracite furnaces of the U. S.? Describe figs. 377, 378. What objections rest against his mode of heating? What excellences have they?

or more apartments, the objections to them are in great measure removed.

703. **Heating by hot water,** distributed in pipes, offers many advantages for the salutary and economical distribution of heat. The high specific heat of water, (600,) enables it to heat over three thousand times its own bulk of air in cooling through a single degree of temperature. That is, one cubic foot of water, by cooling one degree, will raise the temperature of 3,102 cubic feet of air a like amount; for 0·266 : 1 : : 827·437 : 3102. In this proportion the specific heat of air is the first term, and the third term is the bulk of air equal to a unit bulk of water. As hot water is usually distributed in cast-iron pipes, experiments have been made upon the rate of cooling of these pipes, which show that one foot in length of pipe four inches in diameter, will heat 222 cubic feet of air one degree per minute, when the difference between the temperature of the air and the pipe is 125°. The advantage of hot water as a means of heating, depends much on its high capacity for heat, and its slow rate of cooling, by which the temperature declines very slowly, after the fire is extinguished.

For horticultural and manufacturing structures, and other buildings where large pipes are not an objection, it has prominent claims. In private houses, where the hot water pipes occupy a chamber in the basement, and the air is heated by passing among them, all advantage of the radiant heat is lost, and the apparatus becomes comparatively inefficient, and very costly, if a sufficient number of pipes are laid in to do the work.

704. **Perkins' high pressure hot water apparatus.**—The system just named uses water at a very low pressure, never over six lbs. to the square inch. Mr. Perkins has, however, patented a system, in which the hot water is distributed in very small iron pipes, under enormous pressure.

The plan of this system in seen in fig. 379. A coil of pipe, *S*, (1 inch outside and ½ inch inside,) is heated by the fire, *f*. The rising pipe, *t t t*, is carried to the top of the circulation, and in each story or apartment, a coil, *c′ c′*, *c c*, distributes the heat, the water returning by the descending pipe, *t′ t′ t′*, as indicated by the arrows. At the highest point of the circulation is placed a ten inch pipe, called the 'expansion-pipe,' fitted with a cock for the escape of air, and the ad-

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703. What is said of hot water? On what does its excellence depend? Illustrate this. 704. Describe Perkins' high pressure system. What objection exists to it?

mission of water. A sufficient void is left to accommodate the expansion of the water, which is about one-twelfth the whole bulk. Thus arranged, the temperature of the pipes can be raised to any required degree—and in practice they vary from 300° to 550°—*i. e.*, from about 75 lbs. to about 675 lbs. to the square inch. No safety valve is used on this apparatus, and numerous explosions of the fire coil have happened with its use. The high temperature of the pipes endangers buildings, and gives to the air heated by it the empyreumatic, burnt odor, which is so objectionable from cast-iron stoves. It is undoubtedly more efficient than the low pressure hot water system. The system of high pressure *steam* pipes is very similar to this, and equally open to the objection of overheating the air, and endangering buildings from fire.

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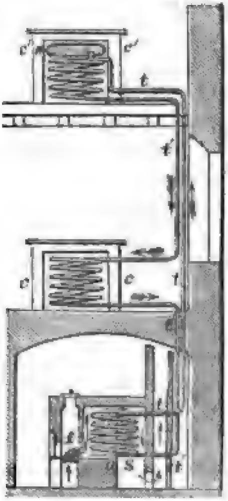

705. Gold's steam heaters.—The radiators.—In this system, the heat is radiated from surfaces of japanned sheet-iron, fastened together by rivets at the bottom of concave depressions in the outer sheet, as seen in fig. 380. This arrangement divides the whole steam space into numerous communicating cells, as seen in the cross section, *D;* the steam arrives from the boiler, fig. 381, under very low pressure, (one pound to the inch,) by the inlet cock, *A*, and the air escapes at an outlet cock in the opposite corner above. The water of condensation returns to the boiler by the same pipe, conveying the steam, which is made sufficiently large for that purpose.

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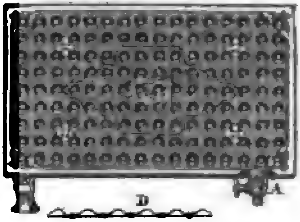

These radiators are placed in the apartments to be heated, either singly or in groups of three or four, concealed under an ornamental screen and covered with marble. The heat, in that case, is both radiant heat and heat of convection. The radiators may also be

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705. What are Gold's radiators? How do they act? What advantage have they?

confined in a space below the apartments, and the air to be warmed passed through or among them, in which case only heat of convection reaches the apartments, as in the common hot-air furnaces. This system is economical of fuel, efficient for the most severe weather, and when combined with a proper system of ventilation, entirely unexceptionable. It has the great merit of securing exactly the desired degree of heat just where it is wanted, however remote from the boiler, and is by means of the air-cock, adjustable to any temperature.

706. **The boiler of Gold's steam heater** is perfectly automatic, and is a beautiful illustration of the ease with which so powerful an agent as steam can be brought under entire self-control and rendered quite free from all danger.

Fig. 381 is an elevation of this boiler, set for use in its masonry, *A*. The water rises in the tube, *J*, which is open to the air, to counterpoise the pressure, which is adjusted to one pound on the inch. *J* is therefore a hydrostatic balance. The ash door, *C*, being closed lower, no air has access to the fire except through the side vent, *E*. This closes by a conical cover at the end of a chain, as soon as the limit of pressure is reached, for then the lever, *F*, rises, by reason of the water pressing up the elastic cover of *F*. A like arrangement, *G*, next opens the upper feed door, *C*; if the fire is not sufficiently held in check by *F*, *C* continues to open until sufficient cold air enters the flues to reduce the steam to its limit and hold it there. The safety valve, *I*, is likewise under the control of a similar arrangement, *H*, which comes into action after *F* and *G*, if needed. *K*, *K*, are the steam-pipes leading to the radiators, and the smoke reaches the chimney by the pipe, *R*. Such nice adjustments secure great economy of fuel, as the combustion cannot proceed faster than the demands of the radiators require.

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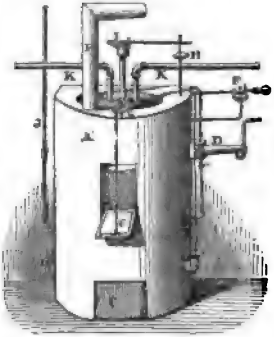

DYNAMICAL THEORY OF HEAT.

707. **Dynamical theory of heat.**—From the constant relation which exists between heat and mechanical force, a strong argu-

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706. How is the boiler made automatic? Describe fig. 381. 707. What is the dynamical theory of heat?

ment has been drawn for the mechanical or dynamical theory of heat, which rests on the supposition that heat is motion. (486.)

708. **Motions of the molecules.**—In this theory it is assumed that the particles of all bodies are in constant motion, and it is this motion which constitutes heat. The kind and quantity of the motion varying with the solid, liquid or gaseous state of the body.

Thus in *solids*, it may be assumed that the molecules are continually oscillating about their position of equilibrium. This motion may be vibration of the constituent atoms of a molecule, or of the entire molecule, and may be rectilinear or rotary.

In *liquids*, the molecules have no constant position of equilibrium, the repulsive and attractive forces being nearly equalized. The movements of the liquid molecules may therefore be either vibratory, rotary, or progressive.

In *gases*, the repulsive force predominating, the molecules move onward in straight lines.

709. **Vaporization.**—The phenomenon of vaporization is explained in the following way, by the dynamical theory of heat.

At the surface of a liquid, a peculiar combination of the different motions, may cause a molecule to be thrown off, and out of the reach of the neighboring molecules, before their attractive force can annihilate its projectile motion. The space above will become more and more filled with these repelled molecules, until equilibrium is obtained, when the number of molecules projected into the space above is equal to the number impinging on and retarded by the surface of the liquid. This is the process of vaporization; it increases with the temperature and diminishes with the pressure, and may take place from the surface, either of a solid or of a liquid. (619.) The limit of vaporization is reached, when the cohesive force of the molecules is more powerful than any combination of molecular movements.

710. **Changes in the state or volume of bodies.**—This view explains the production and consumption of heat, which accompany changes of state or volume in bodies. The work performed is partly internal and partly external.

Thus when a solid is melted, there is an internal work, employed in changing the relative position of the molecules, and in consequence, an absorption of heat proportional to the work accomplished. In evaporation there is an internal work, employed in separating the

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708. What does this theory assume? How does the motion vary? How is it in solids? How in liquids? How in gases? 709. How is vaporization explained on this theory?

molecules, and an external work in overcoming the forces which oppose themselves to the expansion of the vapor.

When, on the contrary, a gas or vapor is liquefied by compression, the external work is supplied, and the internal work due to the cohesive force which draws the atmosphere togther, is transformed into heat. Again, when a liquid solidifies, the internal work which unites the molecules is transformed into heat, and appears as sensible heat.

It is evident that this theory would modify the ideas generally received of the amount of heat in bodies. Thus the heat which is rendered latent, when a solid is liquefied, cannot be regarded simply as being insensible; it must be considered as destroyed, or, more properly, as being converted into motion.

711. **Unit of measurement, the foot-pound.**—In the experiments upon the mechanical equivalent of heat, the unit adopted in England and in this country, is the foot-pound, or the mechanical force expended in raising a pound weight, one foot high. (686.) In France and other European countries, the unit adopted is the mechanical force expended in raising one kilogramme, (2·2056,) one metre, (39·37 in.) high.

712. **Relations of heat and force.**—It has already been stated, (491,) that motion or mechanical force produces heat. When heat is produced, mechanical force is destroyed. The connection between heat and mechanical force appears more intimate, when it is shown that a given quantity of the one may be converted into a determinate quantity of the other. Hence it has been concluded that mechanical force is transformed into heat, and conversely, that heat is transformed into motion, when it is destroyed.

713. **Determination of the mechanical equivalent of heat.**—According to the preceding theory, the mechanical equivalent of heat is independent of the nature of the body by whose agency the transformation of mechanical force into heat is effected; hence the same result should be arrived at, whatever course of experiment is adopted. Mr. J. P. Joule, of Manchester, Eng., has made the most exact determination of the mechanical equivalent of heat in a series of very careful and elaborate experiments, conducted between the years 1840 and 1843. He determined the mechanical equivalent of heat in a number of ways,

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What limits it? 710. How does it explain changes of state or volume? (1.) When a solid is melted? (2.) When a gas is liquefied? How does it affect our views of latent heat? 711. What is the unit of heat measurement? 712. What is the relation of heat to force?

reversing the question, and determining the amount of heat produced by a certain expense of mechanical force.

One method was by the compression of gases; compressing air with a great force in a copper receiver, in one series of experiments filled with air only, and in another with water. The whole apparatus was placed in the water of a calorimeter, whose temperature, before and after the experiment, was carefully determined. The heat developed by the friction of water and of oil, was determined in an apparatus consisting of a brass paddle-wheel, having revolving vanes working between stationary vanes. This wheel was made to revolve by the descent of a known weight, and thus the mechanical force exerted could be determined. A similar apparatus, of smaller size, and made of iron, was used for experiments on mercury. In all cases, the apparatus was placed in a metallic vessel filled with the liquid, and the temperature noted before and after the experiment.

In his experiments on the friction of solids, Mr. Joule used an apparatus consisting of a vertical axis, which carried a beveled cast-iron wheel, against which a fixed cast-iron wheel was pressed by a lever. The whole was plunged in an iron vessel filled with mercury, the axis passing through a hole in the lid. In all of these experiments, the temperatures were noted by thermometers, which indicated a variation of temperature of the one two-hundredth of a degree F.

714. **Results of Joule's experiments.**—In the following table are given the most important results obtained by Mr. Joule. The second column gives the results obtained in air, the third column, the same results corrected for a vacuum.

Material employed.	Equivalent (in foot-pounds) in air.	Equivalent in vacuo.	Mean.
Water, . .	773·640	772·692	772·692
Mercury, .	773·762 776·303	772·814 775·352	774·083
Cast-iron, .	776·997 774·880	776·045 773 930	774·987

715. **Conclusions deduced from the above experiments.**—

1. *That the quantity of heat produced by the friction of bodies is always proportional to the force employed.*

2. *That the quantity of heat capable of increasing the tem-*

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713. What is the relation of the equivalent of heat to the body heated? How did Joule determine the mechanical equivalent of heat by gases? How for liquids? How for solids? 714. What are the results of Joule's experiments?

perature of one lb. of water (weighed in vacuo, and between 55 and 60°) by 1° F., requires, for its evolution, the expenditure of a mechanical force represented by the fall of 772 *lbs. through the space of one foot.*

Consequently a force of one horse power (686) would raise 427 lbs. of water 1° F. each minute, and would bring it to boil from 60° in two and a half hours. Prof. Thomson (Phil. Mag., Feb. 1854) says, it is mathematically demonstrated from the dynamical theory of heat, that any substance may be heated 30° F. above the atmospheric temperature, by means of a properly contrived machine driven by an agent, spending not more than one thirty-fifth of the energy of the heat communicated, and that a corresponding machine, or the same machine worked backwards, may be employed to produce cooling effects.

Where water power abounds, the heat of friction has been used to warm buildings, and an apparatus has been constructed in Paris, in which water is converted into steam by friction solely.

716. **The sources of heat** already alluded to, (491,) might very profitably be here considered at greater length, but want of space compels the omission of anything more under that head, although its discussion would be both interesting and profitable.

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715. What conclusions follow? What is the thermal effect of a horse power?

Electrical machine of Nairne for both electricities.

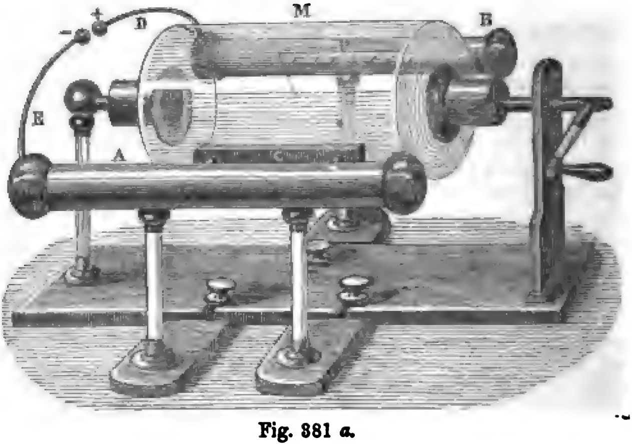

Fig. 381 *a*.

OPTICS.

717. **Optics.—Light.**—Optics, (from the Greek verb, *optomai*, to see,) is that branch of physical science which treats of the nature and properties of light.

Light is the agent which, acting upon the eye, produces the phenomena of vision.

718. **Nature of light.**—In regard to the nature of light, a great diversity of opinion has prevailed among philosophers.

(*a*) *Corpuscular theory.*—Sir Isaac Newton maintained that the phenomena of light are produced by luminous corpuscles thrown off from burning bodies, each particle producing, in its flight, vibrations in the surrounding ether similar to the waves produced by a stone falling into the water.

(*b*) *Undulatory theory.*—Huyghens maintained, in opposition to Newton, that light consisted solely of vibrations in an ethereal medium, without the onward progress of any substance whatever. This theory has been investigated and defended by many of the ablest philosophers; by Young, Malus, Fresnel, Brewster and others, and is now generally received.

The undulations producing the phenomena of sound take place in the same direction that the sound itself moves; but the vibrations of light are supposed to move at right angles to the direction in which light is propagated. It is difficult to explain all the phenomena of light even on this theory.

(*c*) An *oscillatory theory of light* has been recently proposed by Mr. Rankine, of Glasgow.* In this theory, theparticles of luminiferous ether are supposed to rotate on their axes, by the influence of a species of magnetic force, which is wholly destitute of effect in producing resistance to compression, so that it is no longer necessary, as in the undulatory theory, to suppose the luminiferous medium to have the properties of an elastic body. The same mathematical formulæ are employed, with this hypothesis, as for the undulatory theory. Whether this theory can be applied to explain all the phenomena of physical optics, remains to be proved.

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* See transactions of the British Association for 1853, p. 9.

717. From what is the term optics derived? Of what does optics treat? What is light? 718. What was Newton's theory of the nature of light? What was Huyghen's theory? In what respect do these two theories agree? In what respect do they differ? How are the vibrations of light supposed to differ from the vibrations which produce sound? What is the oscillatory theory of light?

719. **Relation of different bodies to light.**—All bodies are either luminous, transparent, translucent, or opaque.

(*a*) Luminous bodies are those in which light originates, as the sun, and burning bodies.

(*b*) *Transparent bodies* allow light to pass freely through them, thus permitting the form of the other bodies to be distinctly seen through them. Such are water, air, and polished glass. Such substances are also said to be *diaphanous*, (from *dia*, through, and *phaino*, to shine.)

(*c*) *Translucent bodies* permit only a portion of light to pass, and in so irregular or imperfect a manner, that the outline of other bodies cannot be clearly seen, as through rough glass and oiled paper.

(*d*) *Opaque bodies* are those which do not ordinarily allow any light to pass through them, as wood and the metals. But all bodies, even the metals, may be made so very thin as to become partially transparent or translucent.

720. **Rays, pencils, and beams of light.**—A single line of light is called a *ray*. A *pencil* of light is a collection of rays diverging from a common source, or converging to a point. A *beam* of light is a collection of parallel rays. Diverging rays are those which gradually separate from each other. Converging rays are those which tend to meet in a common point; hence we have the terms diverging pencils, and converging pencils of light.

721. **Visible bodies emit light from every point and in every direction, the rays diverging from each point in right lines.**

Let *A B C*, fig. 382, be three points in any visible object; from each of these points, light is emitted in diverging pencils, as partially represented in the figure.

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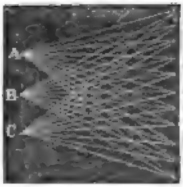

In this figure certain points are seen, where rays from *A B C*, cross each other, and between them are vacant spaces. No such vacant spaces exist, but the rays from all points in the object are crossing each other at every point in the space where the object is visible.

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719. What are luminous bodies? What are transparent bodies? What are translucent bodies? What bodies are called opaque? 720. What is a ray of light? What is a pencil of light? What is a beam of light? What are diverging rays? What are converging rays? 721. In what direction do visible bodies emit light?

722. Propagation of light in a homogeneous medium.—A *medium* is something existing in space, capable of producing phenomena. A medium is called luminiferous, which is capable of transmitting light; and is said to be homogeneous when the composition and density of all its parts are the same. All space is supposed to be pervaded by a luminiferous medium, called *luminiferous ether*, and yet the particles of this ether may act upon each other at great distances. In a homogeneous medium, light always moves in straight lines. If any opaque body is placed in a direct line between the eye and a luminous body, the light is intercepted.

When light enters a dark chamber by a very small opening, the course of the light becomes visible by illuminating the fine particles of dust always floating in the air. Rays of sun-light are thus easily demonstrated to move in straight lines.

723. Velocity of light.—Light travels with such amazing velocity, that for any distances on the surface of the earth, the time occupied in its passage from one point to another is totally inappreciable by ordinary means.

In 1676, Roemer, a Danish astronomer, observed that the eclipses of the first satellite of Jupiter, which occur at uniform intervals of time when the earth is moving in that part of her orbit nearest to, or most remote from Jupiter, are constantly retarded when the earth is moving from that planet, and as regularly accelerated when the distance between the earth and Jupiter is diminishing. He found that when the earth was in that part of her orbit most distant from Jupiter, the eclipses of the first satellite take place 16 m. 36 s. later than when in the opposite part of her orbit.

Foucault's apparatus for measuring the velocity of light.—Notwithstanding the prodigious velocity of light, M. Foucault has succeeded in measuring it, by employing a revolving mirror, according to the method devised by Wheatstone for measuring the velocity of electricity. In describing this apparatus, we shall suppose the properties of mirrors and lenses to be already understood.

The apparatus of M. Foucault is represented in fig. 388. The shutter of a dark chamber is pierced with a square opening, *K*, behind which a fine platina wire, *a*, is stretched vertically. By means

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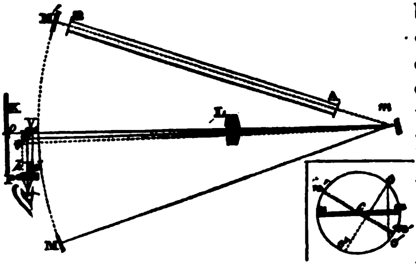
What is a medium? What is a luminiferous medium? What is meant by luminiferous ether? 722. How does light move in a homogeneous medium? How is this demonstrated? 723. What is said of the velocity of light? Who first determined the velocity of light? How did he determine it? Describe Foucault's method of determining the velocity of light.

of a mirror, a beam of solar light is made to enter the chamber, and being divided by the platinum wire, it falls upon an achromatic lens, *L*, of long focus, placed at a distance from the platinum wire less than double the distance of its principal focus. The image of the platinum wire would be formed in the axis of the lens, somewhat enlarged. But the beam of light, after passing the lens, falls upon the plane mirror, *m*, which revolves with great velocity, and being reflected by it, an image of the platinum wire is formed in space, which image is displaced with an angular velocity, double the velocity of the mirror.[*] This image is received by a concave mirror, *M*, so fixed that its centre of curvature coincides with the axis of rotation of the revolving mirror, *m*. The pencil reflected by the mirror, *M*, returns backward and is again reflected by the mirror, *m*, and passes back through the lens, *L*, and forms an image of the platinum wire, coinciding with the wire itself, if the mirror, *m*, revolves slowly. In order to view this image without obscuring the pencil of light which enters the chamber by the opening, *K*, a piece of plate glass, *V*, with parallel faces, is placed between the lens and the platinum wire, inclined in such a manner that the rays reflected fall upon a powerful eye-glass, *P*. If the mirror, *m*, remains stationary, or if it revolves slowly, the returning ray, *M m*, falls upon the mirror, *m*, in the same position it occupied at the first reflection, and returning in the direction it came, it meets at *a* the plate glass, *V*, and is partially reflected and formed in *d*, at a distance, *a d*, equal to *a o*, an image which is seen by the eye by means of the eye-piece, *P*.

388



388 *a*

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[*] To demonstrate this, let *m n*, fig. 388 *a*, be the revolving mirror, *O*, an object placed before it, and forming its image at O'; when the mirror arrives at the position $m'\ n'$, the image will be formed at O''. But the angles, $O'\ O\ O''$, and $m\ c\ m'$ are equal, because their sides are perpendicular to each other. But the inscribed angle $O'\ O\ O''$ is measured by half the arc $O'\ O''$, and the angle $m\ c\ m'$, is measured by the entire arc $m\ m'$; hence the arc $O'\ O''$, is double $m\ m'$, which thus demonstrates that the angular velocity of the image is double the angular velocity of the mirror.

Is the velocity of light the same in all substances?

The revolving mirror, *m*, causes this image to be repeated at each revolution, and if the velocity of rotation is uniform, the image does not change its position. When the velocity does not exceed thirty revolutions per second, the successive appearances of the image are distinct, but when the velocity is greater, the impressions upon the eye are continuous, and the image appears constant.

When the mirror, *m*, revolves with great rapidity, its position is sensibly changed during the interval occupied by the light in passing from *m* to *M*, and back again from *M* to *m*, and the returning ray, after reflection by the mirror, *m*, takes the direction *m b*, and forms an image in *i*; thus the image has deviated from *d* to *i*. Strictly speaking, there is some deviation even when the mirror turns slowly, but it is appreciable only when it has acquired a certain magnitude, by making the rotation of the mirror sufficiently rapid, or by taking the distance, *M m*, sufficiently great. By means of the deviation in the position of the image and the velocity of rotation, the time required for the light to pass from *m* to *M*, and back again, becomes known, making $l = M\,m$, $l' = L\,m$, $r = O\,L$, $n =$ the number of revolutions per second, $E =$ the absolute deviation $d\ i$, and $V =$ the velocity of light per second. M. Foucault obtained the following formula for the velocity of light.

$$V = \frac{8\,\pi\,l^2\,n\,r}{\delta\,(l + l')}.$$

In the experiments of M. Foucault, *m M*, was only about four yards, but by giving the mirror, *m*, a velocity of 600 or 800 revolutions per second he obtained a deviation of from eight one-hundredths to twelve one-hundredths of an inch.

Experiments have been made with the same apparatus to determine the velocity of light in liquids. For this purpose a tube, *A B*, three yards long, is filled with distilled water, or any other liquid, and placed between the revolving mirror, *m*, and the concave mirror, *M'*, similar to *M*. The rays of light reflected by the revolving mirror in the direction, *m M'*, pass twice through the column of fluid in the tube, *A B*, before returning to the mirror, *V*. The returning ray is reflected at *c*, and forms an image at *h*. The deviations of the rays which traverse the liquid are greater than the deviation of the rays which are propagated in air alone, which shows that the velocity of light in fluids is less than in air.

724. **No theory of light is entirely satisfactory.**—In the corpuscular theory of light, advocated by Newton, it was supposed that fluids and solids attracted the light, and refraction was ex-

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724. How does the diminished velocity of light in fluids favor the undulatory theory of light?

plained by supposing that light moves faster in dense bodies than in air, as is known to be the case in regard to sound. According to the undulatory theory, it is known that waves or undulations must move slower in dense bodies than than in rarer media.

The discovery of Foucault, that light actually moves slower in denser media, tends to confirm the undulatory theory.

The immense power of resisting compression which a medium ought to possess, in order to transmit transverse vibrations with a velocity so much greater than the motions of the swiftest planets or comets, is an objection against the undulatory theory that has not yet been satisfactorily answered.

The discussion of the theories of light belongs to the higher departments of mathematics.

725. **Properties of light.**—(*a*) *Absorption.*—Light falling upon any substance is either absorbed, dispersed, reflected, or refracted. If it disappears entirely, it is said to be *absorbed;* as when light falls upon black substances. No substances absorb all the light, for the fact that the blackest substance is still visible, shows that its different parts emit some of the light which they receive.

(*b*) *Dispersion.*—Light falling upon opaque bodies, causes them to become luminous, or to emit light in all directions, and thus become visible. Such bodies are said to *disperse* light, because they scatter the light in all directions from which they are visible.

Bodies owe the property of dispersing light to the innumerable little facets of the particles composing their rough surfaces. Only part of the light is thus irregularly reflected or dispersed, while much of it is probably absorbed or destroyed.

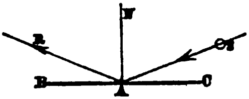
(*c*) *Reflection.*—When light falls upon polished surfaces, or on bodies having naturally smooth and uniform surfaces, it is thrown off in a regular manner, as a ball rebounds from a hard floor.

If a ray of light, *S A*, fig. 384, falls upon a polished surface, *B C*, it will be reflected in the direction *A R*. If *N A* is drawn perpendicular to *B C*, *S A N* will be the angle of incidence, and *N A R* will be the angle of reflection, and the two angles will be equal.

What important objection to the undulatory theory has been mentioned? 725. How is light disposed of when it falls upon any material substance? When is light said to be absorbed? What is the dispersion of light? What occasions the dispersion of light? When is light reflected?

The lines *S A*, *N A*, and *A R*, will all lie in the same plane; we have therefore the following rules:

384



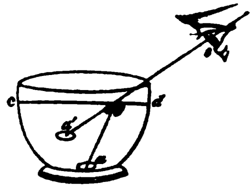
1st.—*The incident ray, the perpendicular at the point of incidence, and the reflected ray, are all situated in the same plane.*

2d.—*The angle of incidence and the angle of reflection are equal.*

(*d*) *Refraction.*—If a straight rod is placed obliquely, partly immersed in water, it appears broken or bent just where it enters the water. If a coin, *a*, fig. 385, is placed in a cup, in such a position that it is just hidden from view, and water is then gently poured into the cup, the coin will appear to be lifted up and will become visible.

Let *c d* be the surface of the water, the ray, *a b*, is so bent or refracted, at the surface of the water, that the coin appears as if placed at *a'*.

385

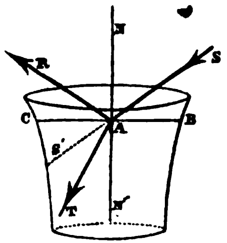


This bending of the rays at the surface of any transparent medium is called *refraction.*

Let *C B*, fig. 386, be the surface of water in a vessel, *S A* a ray of light incident at *A*, and *N A N'* the perpendicular, *A R* the reflected ray, and *A T* the direction of the ray which enters the water and is refracted; then

The angle *S A N* is called the ***angle of incidence*** of the ray *S A*. The angle *N A R* is called the ***angle of reflection***, which is in all cases equal to the angle of incidence. The line *N A N'*, is called the normal. The angle *T A N'* is called the ***angle of refraction***.

386



If we take *A a*, fig. 387, equal to *A b*, and draw *a m* and *b n*, each perpendicular to *N A N'*, then *am* is the ***sine*** of ***the angle of incidence***, and *b n* is the ***sine*** of the angle of refraction, and

$$\frac{am}{bn}$$

is invariably the same for any given medium, whether the angle of incidence is in-

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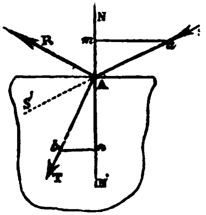
Mention the two principal laws which govern the reflection of light. Explain what is meant by refraction. What is meant by the angle of incidence? What is the angle of refraction? What is the index of refraction? What is the index of refraction for water?—for glass?—for diamond?

creased or diminished; hence the quotient obtained by dividing *a m* by *bn*, is called the *index of refraction.* The index of refraction varies for different media; thus for light passing from air into water, it is about $\frac{4}{3}$, for light passing from air into glass, about $\frac{3}{2}$, and about $\frac{5}{2}$ when light passes from air into diamond. These fractions inverted give the index of refraction for light passing out of water, glass, and diamond, into air.

387



When light passes from a rare to a denser medium, it is reflected towards the perpendicular or normal, and when it passes from a dense to a rarer medium, it is refracted from the perpendicular or normal.

The general law of the refraction of light is thus stated. *The incident ray, the refracted ray, and the perpendicular to the refracting surface at the point of incidence, lie in the same plane; and the sine of the angle of incidence bears a constant ratio,*

$$\frac{am}{bn}$$

in the same medium, to the sine of the angle of refraction.

726. **The amount of light reflected increases with the angle of incidence.**—When light falls upon a transparent medium perpendicular to its surface, nearly all the light enters the medium, and only a small portion is reflected. As the light falls more and more obliquely upon the medium, the amount of light refracted diminishes, and the amount reflected increases.

If we look at the image of the sun in water at midday, and again near sunset, we shall see a remarkable difference. Near sunset the image is so brilliant, the eyes can scarcely bear to look at it, while at midday we observe it without difficulty. The image of objects at a little distance are seen in water more distinctly than the images of near objects, because the light from distant objects falls more obliquely upon the water and a greater amount is reflected.

727. **Internal reflection.**—When light passes through a transparent medium, a portion of the light is reflected at each surface.

In fig. 388, *S A* is a ray of light incident upon the first surface of

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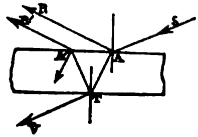
State the general law of refraction. 726. In what position of the incident ray is the greatest amount of light reflected? Why does the image of the sun seen in water appear brighter when it is near the horizon than at midday?

a transparent medium. A portion is reflected in *A R*. *A T* is the refracted ray, and *T V* the emergent ray, but a portion of the light is reflected at the second surface in the direction *T A'*, of which a part emerges in the direction *A' R'*, and a part suffers a second reflection downward from *A'*, and a part emerges, and another portion suffers successive internal reflections before it is either lost by absorption or finally emerges on one or the other side of the medium. In general only the rays *A R*, *T V*, and *A' R'*, have sufficient intensity to be visible to the naked eye.

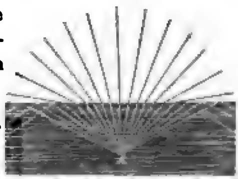
388



728. **Total reflection.**—When light passes from a dense to a rarer medium, the angle of refraction is greater than the angle of incidence, and when the angle of refraction is 90°, the angle of incidence is much less. For water it is 48° 35', for ordinary glass it is 41° 49', consequently a ray of light traversing water or glass at greater angles cannot escape into the air, but is *totally reflected*, obeying the ordinary law of reflection. The proportion of light suffering internal reflection from a surface of glass or water, constantly increases from the perpendicular to the point where total reflection takes place.

Fig. 389 shows light radiating from a point below the surface of water and escaping into the air, the angle of emergence increasing much faster than the angle of incidence, till the light emerges parallel to the surface of the water, after which total reflection takes place.

389



To an eye placed below the surface of the water, all objects above the horizon would be seen within an angle of 97° 10', or double the angle of total reflection for water.

729. **Umbra and Penumbra.**—When an opaque object is held in a pencil of light proceeding from a luminous point, as *s*, fig. 390, a dark and well defined shadow is produced, which increases

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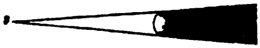
727. What is internal reflection? 728. When is light totally reflected? What are the angles of total reflection in water and glass respectively? How does internal reflection differ at different angles? What is the apparent extent of the visible horizon, to an eye placed below the surface of water? 729. Explain the terms umbra and penumbra.

in size as it becomes more distant. The dark shadow is called an *umbra.* If the light proceeds from a luminous body, having a sensible magnitude, as *A*, fig. 391, besides the dark shadow, or *umbra*, where no part of the luminous body is visible, there will be a much broader partial shadow called the *penumbra*, where a part only of the luminous body is visible. The darkness of the penumbra gradually increases from the extreme border, which is too faint to be easily seen, to the umbra or full shadow, as is shown in a section of the shadow, at fig. 392.

390



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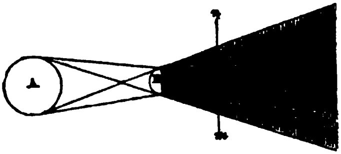

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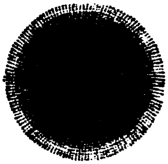

730. **Images produced by light transmitted through small apertures.**—If a white screen is placed near a small opening in a dark chamber, the rays of light which pass through the opening will form on the screen inverted images of external objects.

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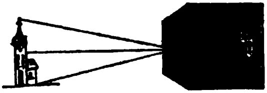

It will be seen in fig. 393, that the rays of light from the top and the bottom of the object cross each other in the small opening, and thus invert the image. If the aperture is small, the image will be formed in the same manner, whatever be the form of the aperture. But if the opening is large, the image will be indistinct, or entirely disappears.

731. **Intensity of light at different distances.**—The intensity of light at any distance from a luminous body, is in an inverse proportion to the square of the distance.

Let *O*, fig. 394, be a luminous point; at 1, 1, place a board one foot square; it will cast a shadow that will cover a space two feet square at double the distance, three feet square at three times the distance, and four feet square at four times the distance. The areas will therefore be, 1, 4, 9, 16, and the intensity of the light at the distances 1, 2, 3, 4, will therefore be in the proportions of 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$.

Is there any clear line of demarkation between the umbra and penumbra? 730. How are images produced by light passing through a small opening? Why is the image inverted? 731. What is the relative intensity of light at different distances from a luminous body?

732. **The absolute intensity of light** from any luminous object, will be equal to the intensity of each luminous point, multiplied by the number of luminous points, and divided by the square of the distance from the luminous object at which it is seen.

A given surface will receive the greatest amount of light when placed exactly facing the luminous object, or when at right angles to the direction of the rays. The amount of light received will diminish in proportion as the illuminated surface is placed inclined to the direction of the rays.

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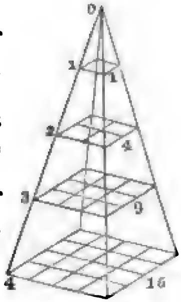

733. **Photometers** are instruments employed to measure the comparative intensity of different lights. The principle on which they are constructed is, to so place the lights that they will illuminate a single surface, or two adjacent surfaces, with equal intensity. The relative intensities of the two lights are then as the square of their distances from the illuminated surfaces.

Bunsen's Photometer is the simplest and most convenient photometer yet invented. A disk of paper four or five inches in diameter, is rendered translucent by washing it with paraffine or stearine, dissolved in oil of turpentine or naphtha, except a spot about an inch in diameter at the centre. When this disk is held between two lights, at a point where their intensity is unequal, the translucent part of the paper is easily distinguished from the central part, but when moved to a point where the two lights have equal intensity, all parts of the paper have a uniform appearance. No light appears to shine through, because the illumination is equal on both sides. By means of a graduated bar, on which the light and disk are mounted, the distance of each light from the paper is determined, and their respective intensities are calculated on the principles above mentioned.

REFLECTION BY SPECULA AND MIRRORS.

734. **Mirrors** are solid bodies bounded by regular surfaces, highly polished, and capable of reflecting a considerable portion of the light which falls upon them.

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732. What is said of the absolute intensity of light? In what position with regard to the light will a plane surface be most strongly illuminated? 733. What are photometers? On what principle are they constructed? Describe Bunsen's photometer, and the method of using it. 734. What are mirrors?

The term mirror is generally applied to reflectors made of glass and coated with an amalgam of tin and quicksilver.

785. **Specula are metallic reflectors,** having a highly polished surface. The best speculum metal consists of 32 parts of copper and 15 parts of the purest tin. Specula are also made both of silver and of steel.

In the use of glass mirrors, a portion of light reflected from the first surface, interferes with the perfection of the image; hence, where the most perfect instruments are required, metallic reflectors are employed. In treating of reflectors, we shall notice only the action of the principal reflecting surface, and use the term mirror to comprehend all regular reflectors.

786. **Forms of mirrors.**—Mirrors are either plane or curved. Curved mirrors may be spherical, elliptical or paraboloid. The properties of elliptical and paraboloid reflectors have been mentioned in sections 405 and 406. A *concave* spherical mirror is a portion of the surface of a sphere, reflecting from the internal side. A *convex* spherical mirror is a portion of the surface of a sphere, reflecting from the outside. Curved mirrors, whether concave or convex, may be regarded as made up of an infinite number of plane mirrors, each perpendicular to a radius drawn through it from the centre of the mirror.

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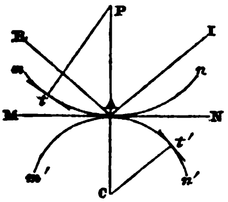

Fig. 395 shows a plane mirror, *M A N*, a concave mirror, *m A n*, and a convex mirror, *m′ A n′*, having a common point, *A*, and the line, *P A C*, perpendicular to each at the point *A*. If a ray of light, *I A*, is incident upon either mirror at the point *A*, the reflected ray, *A R*, will make the same angle with the perpendicular as is made by the incident ray. At any other points, as *t* or *t′*, the curved mirrors will act like little plane mirrors, perpendicular to the radii *P t* and *C t′*.

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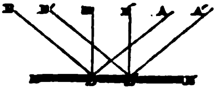
785. What is a speculum? What is the composition of speculum metal? Why are metallic reflectors better than glass mirrors? 786. What are the different regular forms of mirrors? How do concave and convex mirrors differ from each other? How may convex mirrors be regarded? How can plane concave and convex mirrors be placed so as to have a common perpendicular? What is the perpendicular to a concave or convex spherical mirror?

737. **Reflection by plane mirrors.**—*Parallel rays* of light, falling upon a plane mirror, will be parallel after reflection.

If parallel rays of light, *A D*, *A' D'*, fig. 396, fall upon the plane mirror, *M N*, they will each make equal angles with the perpendiculars, *E D*, *E' D'*, and as the angles of incidence and reflection will be equal, the reflected rays, *D B*, *D' B'*, will make equal angles with the perpendiculars, and will consequently be parallel after reflection.

396



If *A D* represent the upper side of the beam of light before reflection, it will become, after reflection in *D B*, the lower side of the beam. Hence a beam of parallel light is inverted in one direction by reflection from a plane mirror.

Diverging rays of light, falling upon a plane mirror, will continue to diverge after reflection, and will appear to emanate from a point as much behind the mirror as the luminous point is before it. Let *A* be a radiant point in front of the plane mirror *M N*, fig. 397. If the perpendicular, *E D*, *E' D'*, *E'' D''*, be drawn, the reflected rays will make the same angles with the perpendiculars as the incident rays, and hence the reflected rays will make the same angles with each other as they did before reflection, but they will appear to diverge from the point *A'*, behind the mirror.

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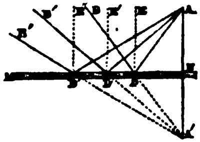

Converging rays continue to converge after reflection from a plane mirror. After reflection they will converge towards a point as much in front of the mirror as the distance of the point behind the mirror, towards which they converged before reflection.

This is easily seen by tracing the rays of light backward in the preceding figure. Reflection from a plane mirror changes the direction of the rays of light, and removes the point of apparent convergence or divergence to the opposite side of the mirror.

738. **Images formed by plane mirrors.**—Let *M N* be an object placed in front of the plane mirror, *A B*, fig. 398, and *E* the place of the eye. From the great number of rays emitted in every direction from *M N*, and reflected from the mirror, a few only can enter the eye at *E*. These will be reflected from those por-

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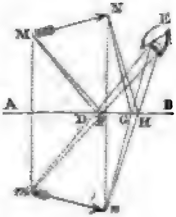
737. How are parallel rays reflected by a plain mirror? How are diverging rays reflected? How are converging rays reflected?

tions, *D F*, *G H*, of the mirror, so situated with respect to the eye and the points, *M N*, that the angles of incidence and reflection will be equal. If the rays, *D E*, *F E*, are continued backward, they will meet at *m*, and they will appear to the eye to radiate from that point. In the same manner the rays *G E*, *H E*, will appear to radiate from *n*; a virtual image of the object will therefore be formed between *m* and *n*.

398



This is called a *virtual* image, because it is not formed of rays of light actually coming from the position of the image, but by rays so changed in their direction, that they appear to the eye as though originating from an object situated at *m n*, behind the mirror.

If the eye is moved about, the image remains stationary, hence it is seen by means of rays reflected from other parts of the mirror. Two or more persons may see the image at the same time and in the same position, but by different rays of light.

The position of the image behind the mirror may be found by drawing lines from prominent points in the object, perpendicular to the mirror, extending them as far behind the mirror as the points from which they are drawn are situated before it, then uniting the extremities of the lines, the outlines of the image will be delineated. The images of all objects seen in a plane mirror have the same form and distance from the mirror as the objects themselves.

739. **Images multipled by glass mirrors.**—Glass mirrors produce several images. This may be readily demonstrated by looking very obliquely at the image of a candle in a glass mirror. The first image, caused by partial reflection from the first surface of the glass, is comparatively faint. The second image is formed by reflection from the quicksilver, which covers the second surface, and is very clear and distinct.

When rays of light from any object fall upon the first surface

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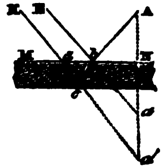
738. How are images formed by a plane mirror? What is meant by a virtual image? How can the position of the image formed by a plane mirror be determined? At what distance is the image formed by a plane mirror? 739. Why does a glass mirror produce more than one image of an object? From which surface of a glass mirror does the greatest amount of reflection take place?

of a plate of glass, *M N*, fig. 399, a portion of the light being reflected, forms the first image, *a*. The principal part of the light penetrates the glass, and is reflected at *c*, by the silvering which covers the back of the mirror, and coming to the eye in the direction *d H*, produces the image, *a′*, at a distance from the first image equal to twice the thickness of the glass. This image is much brighter than the first, because the metallic coating of the mirror reflects a greater amount of light than the first surface of the glass.

399

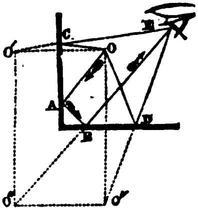


Other images, more and more obscure, are formed by rays which emerge from the glass after successive interior reflections from the two surfaces of the glass. As this multiplicity of images diminishes the distinctness of vision, metallic reflectors are often employed in optical instruments.

740. **Images repeated by inclined reflectors.**—When an object is placed between two mirrors, which make with each other an angle of 90° or less, several images are produced, varying in numbers according to the inclination of the mirrors. If they are placed perpendicular to each other, three images will be seen, situated as in fig. 400.

The rays *O C* and *O D*, from the point *O*, form, after a single reflection, one, the image, *O′*, the other, the image O″; and the ray *O A*, which undergoes two reflections at *A* and *B*, gives a third image, *O‴*. When the inclinations of mirrors is 60°, five images are formed; and when they are placed at an angle of 45°, seven images are produced. The number of images continue to increase as the inclination of the mirrors diminishes, and when the mirrors become parallel, the number of images is *theoretically* infinite, but as some of the light is lost at every reflection, and the successive images appear more and more distant, only a moderate number of images are visible.

400



741. **Kaleidoscope.**—This beautiful toy is formed by placing

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Explain fig. 399. Why is a glass mirror inferior to a metallic reflector? 740. How are images multiplied by two inclined mirrors? How many images are formed by two plane mirrors inclined to each other at an angle of 60°? At 45°? At what inclination should two plane mirrors be placed to produce the greatest number of images of a single object?

two mirrors, inclined at an angle of 45°, in a paper tube, closed at one end by plain glass, and at the other by ground glass. In this tube, between the mirrors, are placed fragments of various objects, such as colored glass, tinsel, &c. Looking into the end covered with plain glass, seven images of every object are seen, symmetrically arranged. On moving the tube, so as to change the position of the objects, a series of beautiful changes take place, perfectly incomprehensible to those who do not understand the structure of the instrument. The mirrors in the kaleidoscope may be placed at other angles, when they will give a different number of images of objects within.

742. **Intensity of reflected light.**—The amount or intensity of the light reflected regularly by any surface, increases with the degree of polish, and also with the enlargement of the angle of incidence.

If we look very obliquely at a sheet of white paper, placed before a candle, an image of the flame may be seen reflected from the surface of the paper, but the image disappears when the rays fall upon the paper nearer to the perpendicular.

Different substances, polished with equal care, differ in their power of reflecting light. The amount of light reflected depends also upon the nature of the medium in which the reflecting body is placed. Bodies immersed in water reflect less light than in air.

743. **Irregular reflection.—Diffused light.**—The reflection from polished surfaces, which follows the two laws already announced, is called *regular reflection;* but only a part of the light is reflected regularly from any surface, when the reflecting body is more dense than the surrounding medium. A part of the light is scattered in all directions, and is said to be *irregularly reflected* or *diffused.* This is the portion of light which renders an object visible. Light regularly reflected gives an image of the object which *emits* the light, while light irregularly reflected gives only an image of the body which *reflects* it. When a mirror becomes dim by the accumulation of light dust, or anything which tarnishes its surface, the amount of regular reflection diminishes,

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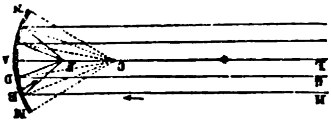
741. Explain the theory of the kaleidoscope? 742. What circumstances affect the intensity of light reflected from a polished surface? 743. What is meant by irregular reflection? How does light render objects visible? What effect is produced by dust accumulated on a polished surface?

and the irregular reflection increasing, all parts of the mirror become distinctly visible.

744. **Concave and convex spherical mirrors.**—If an arc of a circle, *M N*, fig. 401, is made to revolve around a line, *A C L*, drawn through its centre of figure *A*, and its centre of curvature *C*, it will generate a curved surface, which will be a segment of the surface of a sphere. Internally, such a surface is called a concave mirror, and externally a convex mirror. The line, *A C*, is called the principal axis of the mirror, and any other line drawn through the centre of curvature, *C*, is called a secondary axis. The angle, *M C N* is called the angular aperture of the mirror. A section made by a plane passing through the principal axis, *A C*, is called the principal section, or a meridional section.

401



The theory of reflection from curved mirrors is easily deduced from the laws of reflection by plane mirrors. Every point in the curved mirror may be regarded as a point in a plane mirror so situated that its perpendicular, where the ray of light falls upon it, coincides with the radius of the curved mirror at that point.

A line drawn from any point in a spherical mirror to the centre of curvature, will be perpendicular to the mirror at that point, and also perpendicular to any plane mirror touching the curved mirror at that point.

745. **Foci of concave mirrors.**—The focus of a curved mirror is the point towards which the reflected rays converge.

Parallel rays falling upon a concave mirror, fig. 401, converge, after reflection, to a point equi-distant between the mirror and the centre of the sphere, of which the mirror forms a part. This point is called *the principal focus.*

Rays of light emanating from the principal focus of a concave mirror, will be reflected parallel to each other.

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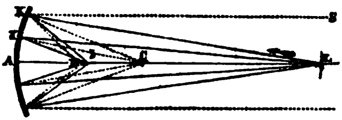
744. What are spherical mirrors? Explain the difference between concave and convex mirrors. What is the principal axis of a mirror? What is meant by the principal section of a mirror? What is the perpendicular to a spherical mirror? How can the reflection from curved mirrors be explained by the laws of reflection from plane mirrors? 745. What is the focus of a concave mirror? What is the principal focus of a concave mirror?

Demonstration.—The lines, *C M, C B, C D*, fig. 401, drawn from the centre of curvature of the mirror, *M N*, are perpendicular to the mirror at those points. The parallel rays, *H B, G D*, will converge, after reflection, to the point *F*. It is evident that the angle of reflection, *C D F*, for any ray, will be equal to the angle of incidence, *G D C;* but *G D C* is equal to *D C F*, which is the alternate angle formed by a line, *D C*, meeting two parallel lines, *G D, L A;* hence in the triangle, *C F D*, the angles, *F C D* and *F D C*, are equal, and therefore the sides, *C F* and *F D*, are equal. If the point, *D*, gradually approaches the point, *A*, $C F + F D$, will differ less and less from *C A*, till their sum will be sensibly equal to *C A*, or *F A* will be sensibly equal to one-half of *C A*, and the focus of parallel rays, after reflection from a concave mirror, will be equal to one-half the radius of curvature. If the point of incidence, *D*, recedes from *A* towards *M*, or *N*, the point, *F*, will gradually approach *A*, or the focal distance will diminish. A concave spherical mirror will therefore only reflect parallel rays to a single focal point when the diameter of the mirror is small. Practically it is found that the diameter of the mirror, or the angular aperture, *M C N*, should not exceed 8 or 10 degrees.

Conjugate focus.—If rays of light falling upon a concave mirror diverge from a point beyond the principal focus, they will converge, after reflection, to a point between the principal focus and the centre of curvature. This point of convergence is called the conjugate focus, because the distance of the radiant point and the focus to which the rays converge, after reflection, have a mutual relation to each other.

Let rays diverging from a point, *L*, fig. 402, fall upon a concave mirror, the angle of incidence, *L K C*, will be smaller than *S K C*, the angle of incidence for parallel rays falling upon the mirror at the same point. The angle of reflection, *C K l*, will also be smaller than *C K F*; hence the ray, *L K*, will be so reflected as to cross the principal axis

402



How are rays of light reflected which diverge from the principal focus of a concave mirror? Explain these principles by reference to figure 421. What is the angular aperture of a concave mirror? What is meant by a conjugate focus of a concave mirror? Where should the radiant point be placed to have all the rays fall perpendicularly upon a concave mirror? Where is the conjugate focus when the radiant point is between the centre of curvature and the principal focus?

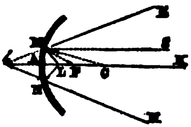
at a point, *l*, between *F*, the principal focus, and *C*, the centre of curvature of the mirror.

If the luminous point is removed to *l*, the reflected rays will meet at *L*. If the luminous point is placed at the centre of curvature, *C*, all the rays will fall perpendicularly upon the mirror, and be reflected back to the point *C*, from whence they came.

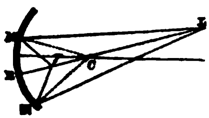
If the luminous point is situated between the centre of curvature and the principal focus, the conjugate focus will be removed beyond the centre of curvature, and become more and more distant as the luminous point approaches the principal focus. When the luminous point arrives at the principal focus, the conjugate focus will be removed to an infinite distance, or, in other words, the reflected rays will become parallel. While the radiant point has removed from *C* to *F*, the conjugate focus has removed from *C*, to an infinite distance.

Virtual focus.—If the radiant point passes from the principal focus, *F*, towards the mirror, as in fig. 403, it is evident that the reflected rays will *diverge*, as though emanating from a point *l*, behind the mirror, called the *virtual focus*.

403



404



When the radiant point is near the principal focus, between it and the mirror, the virtual focus of the divergent reflected rays will be at a very great distance. As the radiant point continues to approach the mirror, the virtual focus also approaches it. While the radiant point passes from the principal focus to the mirror, the conjugate virtual focus, or point from which the reflected rays appear to diverge, passes from an infinite distance behind the mirror, to the surface of the mirror, or to the radiant point itself.

746. **Secondary axes.—Oblique pencils.**—If the luminous point, *L*, fig. 404, is not situated in the principal axis of the mirror, a line drawn from the radiant point through the centre of curvature, as *L C B*, will constitute a *secondary axis*, and the focus of the *oblique pencil* of rays diverging from *L*, will be

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Where is the conjugate focus when the luminous point is in the principal focus? Explain the use of the term virtual focus. How does the position of the virtual focus vary with the movement of the radiant point? 746. What are the secondary axes? How are the foci of oblique pencils determined?

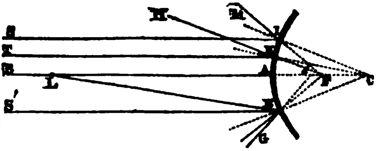
found in this secondary axis. In the same manner we may draw secondary axes, and determine the foci, whether real or virtual, for any number of points in a luminous object.

747. **Rule for conjugate foci of concave mirrors.**—*Multiply the distance of the radiant point from the mirror, by the radius of curvature, and divide this product by twice the distance of the radiant point, minus the radius of curvature of the mirror, and the quotient will be the conjugate focus required.*

If the quotient given by this rule is negative, or if twice the distance of the radiant point is less than the radius of curvature, the conjugate focus will be a virtual focus behind the mirror, and the reflected rays will diverge.

748. **Convex reflectors.**—The effects attending the reflection of diverging, converging, or parallel rays of light by convex reflectors, are, in general, the opposite of the effects produced by concave reflectors. The foci of parallel and diverging rays of light, reflected by a convex reflector, are at the same distance as for concave mirrors, but they are situated behind the reflector, and are, hence, only virtual foci. Light converging towards any point behind a convex mirror, more distant than the principal focus, or focus of parallel rays, will diverge, after reflection, from a virtual focus nearer than the principal focus. Rays converging toward the principal, virtual focus, will be reflected parallel; but rays converging towards a point nearer to the mirror than the principal focus, will be reflected to a real focus in front of the convex reflector. These phenomena will be readily understood by an examination of fig. 405. The ray *S I*, is reflected in the direction *F I M; L E*, is reflected in the direction *l E G*, and reciprocally *G E* is reflected in the direction *G L*, and *M I* in the direction *I S.*

405



749. **Images formed by concave mirrors.**—The principles already explained enable us to understand the formation of images by concave mirrors. Let *A B*, fig. 406, represent an object placed

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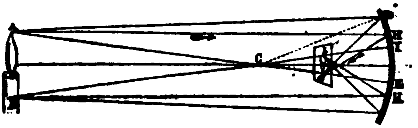
747. State the rule for determining the conjugate focus of a concave mirror when the position of the radiant point is known. When is the conjugate focus real, and when is it only virtual? 748. How does the action of convex reflectors differ from concave reflectors? Where is the principal focus of a convex mirror? Explain fig. 405.

before a concave mirror, beyond its centre of curvature. The lines, *A C* and *B C*, drawn through the centre of curvature from the extremities of the object, are the secondary axes in which the extremities of the image, *a b*, will be formed, at a distance from the mirror equal to the conjugate foci for the extreme points of the object. This image is real, inverted, smaller than the object, and placed between the centre of curvature and the principal focus.

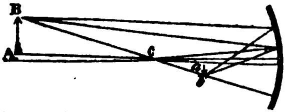
406



If *a b* is regarded as the object, placed between the centre of curvature and the principal focus, an enlarged image will be formed at *A B*. If the object is placed at the principal focus, no image will be formed, because the rays from each point of the object will be reflected parallel to an axis drawn through the centre of curvature from the points where they originate.

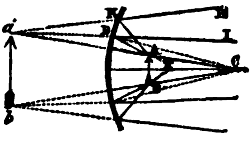
If the object is placed entirely on one side of the principal axis, as in fig. 407, it is evident that its image will be formed on the opposite side of the principal axis.

407



750. **Virtual images.**—If the object, *A B*, fig. 408, is placed between the mirror and the principal focus, the incident rays, *A D*, *A K*, take, after reflection, the directions, *D I*, *K H*, and their prolongations backward, form at *a*, a virtual image of the point *A*. In the same manner the image of *B* is formed at *b*, so that the image of *A B* is seen at *a b*. The image, in this case, is a virtual image, erect, and larger than the object.

408



From the preceding illustrations, it is evident, that, when an object is placed before a concave mirror, more distant than the centre of curvature, the image is real, but inverted, and smaller than the object; as the object approaches the centre of curvature,

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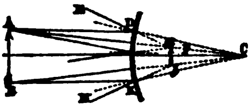
749. Explain the formation of images by concave mirrors. Why is the image formed by a concave mirror inverted? 750. What is meant by a virtual image? When is the image smaller, and when is it larger than the object? Is a virtual image formed by a concave mirror erect, or is it inverted?

the image enlarges and becomes equal to the object and coincides with it; when the object approaches nearer to the mirror than the centre of curvature, the image becomes larger than the object, and more distant from the mirror. When the object arrives at the principal focus, the image becomes infinitely distant, and disappears entirely: when the object approaches nearer to the mirror than the principal focus, an erect virtual image, larger than the object, appears behind the mirror.

751. **Formation of images by convex mirrors.**—Let *A B*, fig. 409, be an object placed before a convex mirror, at any distance whatever. If we draw the secondary axes, *A C*, *B C*, it follows, from what has been said (748) concerning the construction of foci in convex mirrors, that all the rays emitted from the point, *A*, diverge after reflection, and that their prolongations backward converge to a point, *a*, which is a virtual image of the point, *A*. In the same manner, rays emitted from the point, *B*, form a virtual image of that point in *b*.

409



Whatever may be the position of an object before a convex mirror, the image is always formed behind the mirror, erect and smaller than the object.

752. **General rule for constructing images formed by mirrors.** To construct the image of a point; 1. *Draw a secondary axis from that point;* 2. *Take from the given point any incident ray whatever;* 3. *Join the point of incidence and the centre of curvature of the mirror by a right line; this will be the perpendicular at that point, and will show the angle of incidence;* 4. *Draw from the point of incidence, on the other side of the perpendicular, a right line, which shall make with it an angle equal to the angle of incidence. This last line represents the reflected ray, which being prolonged till it crosses the secondary axis, determines the place where the image of the given point is formed.* 5. *Determine the position of any other point in the object in the same manner.*

753. **Spherical aberration of mirrors.—Caustics.**—The rays from any point of an object, placed before a spherical mirror, concave, or convex, do not converge sensibly to a single point,

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751. What kind of images are formed by concave mirrors? How does the size of an image formed by a convex mirror compare with the size of the real object? 752. Describe the method of constructing the image of an object placed before a curved mirror.

unless the aperture of the mirror is limited to 8° or 10°. If the aperture of the mirror is larger than this, the rays reflected from the borders of the mirror meet the axis nearer to the mirror than those which are reflected from portions of the mirror very near to the centre. There results, therefore, a want of clearness or distinctness in the image which is designated *spherical aberration by reflection.*

The reflected rays cross each other successively, two and two, and their points of intersection form in space a brilliant surface, called *a caustic* by reflexion, curving towards the axis, as shown in fig. 410, where *C* is the centre of curvature, *F* the principal focus, and *d* the centre of figure. The curve formed by the intersections of successive rays, is called a *caustic by reflection.*

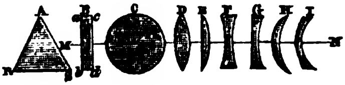
410

REFRACTION IN BODIES HAVING REGULAR FORMS.

754. **Prisms and lenses**, are bodies having certain regular forms, sections of which are shown in fig. 411.

A *prism* is a solid having three or more plane faces, variously inclined to each other, as shown at *A*, fig. 411. The angle formed by the faces, *A R*, *A S*, is the refracting angle of the prism. For some purposes prisms are used having more than three plane faces.

411



A *plane glass*, *B*, is a plate of glass having two plane surfaces parallel to each other.

A *sphere*, shown in section at *C*, has all parts of its surface equally distant from a certain point within, called the centre.

A *double convex lens*, *D*, is a solid bounded by two convex surfaces, which are generally spherical.

A *plano convex lens*, *E*, has one of its surfaces plane, and the the other convex.

A *double concave lens*, *F*, has two concave surfaces opposite to each other.

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753. What is meant by spherical aberration of mirrors? How are caustic curves formed by reflection? 754. What is a prism? What is the reflecting angle? What is a plane glass? What is a sphere? What is a double concave lens?

A *plano concave lens*, *G*, has one of its surfaces plane, and the other concave.

A *meniscus*, shown at *H*, has one surface convex, and the other concave, their curvatures being such, that the two surfaces meet, if continued. As this lens is thicker in the centre than at its edges, it may be regarded as a convex lens.

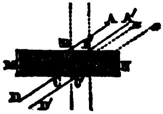
A *concavo convex lens*, shown at *I*, has one surface concave, and the other convex, but the curvatures are such that the surfaces, if continued, would never meet. As therefore the concavity exceeds the convexity, it may be regarded as a concave lens.

If the figures *C*, *D*, *E*, *F*, *G*, *H*, *I*, were revolved around the the axis, *M N*, they would severally describe the solid lenses they are intended to represent.

In explaining the properties of lenses, and showing the progress of light through them, we make use of such sections as shown in the figure, for every plane passing through the axis has the same form, and what is true of one section is true of all.

755. **Plane glass.**—*If parallel rays of light* are transmitted obliquely through glass or any other transparent medium bounded by parallel faces, as *M N*, fig. 412, the rays *A B*, *A' B'*, will be refracted towards the perpendicular, on entering the medium, and emerging at *C*, *C'*, they will be refracted from the perpendicular, and take the directions, *C D*, *C' D'*, parallel to each other, and parallel to their directions before entering the medium. The displacement, *A a*, *A' a'*, is the lateral aberration produced by transmission through a homogeneous medium bounded by parallel surfaces. The amount of lateral aberration increases with the thickness of the medium, and it also increases with the obliquity of the incident rays.

412

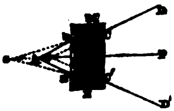


Diverging rays, transmitted through a plane glass, appear, after refraction, to diverge from a point nearer to the glass, as shown in fig. 413. If the rays, *C D*, *C' D'*, are continued backward, they meet in a point, *b*, nearer to the glass than the point, *A*, from which they originated, while rays in the glass appear to diverge from a point more distant than their real origin.

What is a plano concave lens? What is a meniscus? What is a concavo convex lens? In treating of lenses why is it only necessary to consider a single section? 755. How are parallel rays of light affected by transmission obliquely through plane glass? What change do diverging rays undergo? How does the depth of water appear as compared with its real depth?

Objects seen in water will therefore appear to the observer nearer than they really are. Water is about one-third deeper than it appears to be when the observer looks down into it, the bottom appearing to be raised up. To an observer looking from a dense to a rarer medium, objects appear more distant than they really are.

413

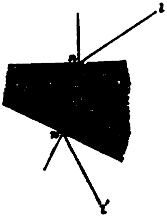


Converging rays, transmitted through a plane glass, or other dense medium bounded by parallel surfaces, will, for the same reason, converge to a point more distant than if the dense medium were not interposed.

This will be evident by tracing the rays, *D C*, *D' C'*, fig. 413, in the opposite direction from what we have previously considered.

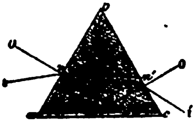
756. **Refraction by prisms.**—If a ray of light, *l n*, fig. 414, falls obliquely upon a transparent medium, whose opposite plane faces are not parallel, the ray will be refracted at the first surface, and take a direction nearer to the perpendicular. Now if the position of the incident ray, and the inclination of the faces of the medium, are as shown in the figure, it is obvious that the emergent ray, *n' l'*, will be turned still further from its original direction. It is evident that any other position of the second refracting surface would cause a corresponding alteration in the direction of the emergent ray.

414



Let *a b c*, fig 415, be a section of a triangular prism, *l n*, a ray of light incident at *n*, *O n s*, the perpendicular at that point, *n n'* will be the course of the ray of light through the prism, and *n' l'* the emergent ray. If the prism is more dense than the surrounding medium, the light will enter the prism, whatever may be the angle of incidence, but if the angle of incidence, *l n O*, diminishes, then the ray, *n n'*, will fall more and more obliquely upon the second surface of the prism, till it arrives at an inclination where it will suffer total internal reflection.

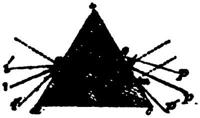
415



How do objects appear when seen through a medium less dense than that where the eye is placed? How does a plane glass affect converging rays? 756. How is a ray of light changed by transmission through a dense medium bounded by surfaces not parallel?

If the incident ray, *l n*, fig. 416, falls upon the prism at such an angle, that, after refraction, it takes the direction, *n n'*, parallel to *a c*, the base of the prism, the angles at which it enters and leaves the prism, will be equal, and the deviation of the emergent ray from the course of the incident ray, will be the least possible. The ray, *l' n*, will emerge in the direction *m p'*, and *l'' n* will emerge in the direction *o p''*, each deviating more from the direction of the incident ray than *n' p* deviates.

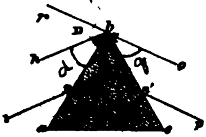
416



If a candle is viewed through a triangular prism, on slowly turning the prism about its axis, a certain position will be found where the apparent position of the candle differs least from its real position. In whichever direction the prism is now turned, the difference between the real and apparent position of the candle increases.

757. Method of determining the index of refraction.—Let *l n n' p*, fig. 417, be the direction of the ray of light when the deviation caused by the prism is a minimum. Draw *h b* parallel to the incident ray, *l n*, and *r b o* parallel to the emergent ray, *n' p*. Let $D = h\ b\ r$, the entire deviation caused by the prism; $d = h\ b\ n$, the complement of the angle of incidence; $g = a\ b\ c$, the refracting angle of the prism; $q = n'\ b\ o = c\ n'\ p$, the complement of the angle of emergence. In this case the angles of incidence and emergence are equal, hence $d = q = 90° - i$, i being the angle of incidence, $D = 180° - (d + g + q)$ substituting in this equation the values of d and q, we have $D = 2\,i - g$, and $i = \frac{1}{2}(D + g)$. Let x and y, as in fig. 415, represent the angles formed with the perpendiculars by the ray traversing the prism, $x + y = g$, and when the angles of incidence and emergence are equal, $x = y$. If n equals the index of refraction, we shall have,

417



$$n = \frac{\sin.\ i}{\sin.\ x}, \text{ or } n = \frac{\sin.\ \frac{1}{2}(D + g)}{\sin.\ \frac{1}{2}\,g}.$$

Now when the angle of minimum deviation and the reflecting angle of the prism are measured, this formula enables us at once

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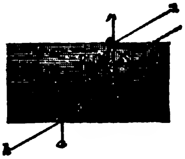
Can light be transmitted through a prism at all angles? Why not? When is the deviation caused by a prism a minimum? 757. How may the index of refraction be practically determined?

to determine the index of refraction. In this manner the index of refraction of any substance is easily determined.

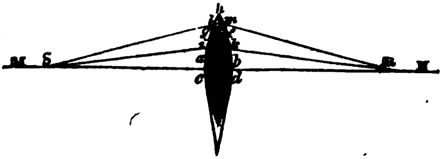
758. **Light passing through parallel strata of different media.** If a ray of light passes through a dense medium, bounded by parallel surfaces, and then enters another medium still more dense, it will undergo still further refraction by the second medium, as shown by the ray, *i c b a h*, fig. 418. If the second medium is also bounded by parallel faces, the emergent ray, *a h*, will be parallel to the incident ray.

418



759. **A double convex lens** may be regared as composed of a number of segments of prisms, the faces of each prism more inclined as we proceed from the centre to the borders of the lens, as shown in fig. 419. The central portion, *a b c d*, may be regarded as a plane glass, having its faces, *a c*, *b d*, parallel, *a g f b* has its face, *a g*, inclined towards *f b*, and the triangular prism, *g h f*, has its sides still more inclined. Now since the deviation of any ray passing through a prism increases as the inclination of the two faces of the prism increases, *s l* will deviate more than *s i*, and if the form of each prism is properly adjusted to its distance from the axis, *M N*, the rays, *s l* and *s i*, or any number of rays, may be made to meet at a common point, *R*, in the axis *M N*.

419



If the segments of prisms, of which we suppose such a lens to be composed, are made sufficiently small, so that each face shall receive but a single ray of light, the sides of the successive prisms will form a regular curve, which, if the lens be of small diameter, will correspond almost exactly with a segment of a sphere.

On account of the impossibility of grinding lenses of any other form with sufficient accuracy for scientific purposes, all lenses are made with either spherical or plane surfaces.

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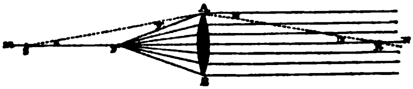
758. Describe the effect of parallel strata of different media. 759. To what may the form of a double convex lens be compared? What is the axis of a lens? What are spherical lenses? Why are only spherical lenses used?

In treating of lenses in the following pages, we shall suppose them made of glass whose index of refraction is one and a half. The slight variations from the results here given, caused by using media of other refractive power, can only be discussed in more elaborate treatises.

Parallel rays of light falling upon a convex lens, *A B*, fig. 420, will be refracted to some point, as *F*, on the other side of the lens. The distance of the focus, *F*, from the lens, will depend upon the amount of curvature, and also upon the refractive power of the substance, of which the lens is composed. If the two surfaces of the lens have the same curvature, and the index of refraction, as for ordinary glass, is one and a half, the focus of parallel rays, called the *principal focus*, will be at a distance from the lens equal to the *radius of curvature* of either surface of the lens.

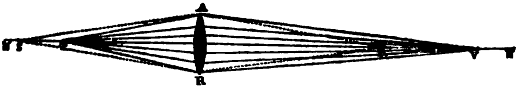
420



Diverging rays.—If the rays falling upon the lens come from a point, *R*, at a distance from the lens equal to twice the principal focus, they will converge to a point, *S*, at an equal distance on the other side of the lens.

It will be easily seen from the figure, that the angles, *X* and *Z*, are equal to each other, (being the alternate angles formed by the straight line, *R A*, meeting two parallel lines,) and also that the angles, *X* and *O*, are equal. In the triangle, *A S F*, the sides, *F A* and *F S*, are equal, hence the angles, *O* and *y*, are equal, and *y* equals *z*, therefore if the incident ray is bent inward to a distance represented by the angle, Z, the refracted ray must be bent outward by an equal angle, *y*, by which means the radiant point is removed from *F*, the principal focus of parallel rays, to *S*, which is at double the distance of *F*.

421



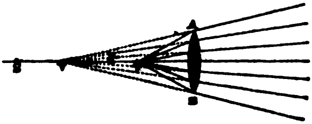
If the radiant point is taken more distant than *R*, as at *V*, fig.

What is the index of refraction of common glass? On what does the length of the focus of a lens depend? What is meant by the principal focus of a lens? At what distance is the principal focus of a double convex lens? Explain the action of a lens upon diverging rays?

421, the conjugate focus will be removed from *S*, to some point, *T*, between *S* and the principal focus.

If rays of light falling upon the lens, *A B*, fig. 422, converge towards a point, *V*, before refraction, they will converge, after refraction, towards a point, *T*, between the principal focus, *F*, and the lens. Conversely, if rays of light diverge from a point, *T*, between the lens and its principal forms, they will diverge after passing through the lens, from a virtual focus, *V*, more distant than the principal focus.

422

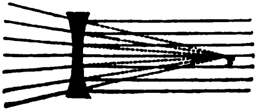


760. **Plano convex lenses.**—The action of a plano convex lens is in general the same as that of the double convex lens, but its foci are at double the distance, the principal focus being at a distance equal to twice the radius of the curved surface.

761. **Concave lenses.**—A concave lens produces, upon rays of light transmitted through it, an effect the opposite of that produced by a convex lens.

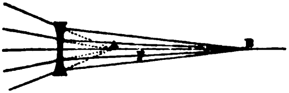
Parallel rays of light, transmitted through a double concave lens, diverge from a virtual focus in front of the lens, as shown in fig. 443; the virtual focus being at the centre of the sphere of which the first surface forms a part. This is its principal focus.

423



Diverging rays.—If the radiant point is more distant than the principal focus, as at *B*, fig. 424, the virtual conjugate focus, *A*, will be between the principal focus, *F*, and the surface of the lens, and the rays will diverge after refraction.

424



Converging rays, transmitted through a concave lens, will be rendered less convergent, parallel, or divergent, depending upon the distance of the point towards which they converge before entering the lens.

762. **Rules for determining the foci of lenses.**—When lenses

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If the radiant point is more distant than the principal focus where will the conjugate focus be situated? What is the action of a convex lens on converging rays? 760. Where is the principal focus of a plano convex lens? 761. What is the effect of a concave lens upon parallel rays? On diverging rays? On converging rays?

are made of glass whose refractive index is one and a half, their foci may be determined by the following rules:

RULE FOR THE PRINCIPAL FOCUS.

Divide twice the product of the radii by their difference for the meniscus and concavo convex lenses, and by their sum for the double convex and double concave lenses. The quotient will give the focus for parallel rays. The focus of parallel rays, or principal focus, of the plano convex or plano concave lens, is double the radius of curvature.

RULE FOR THE CONJUGATE FOCUS, WHEN THE FOCUS OF THE INCIDENT RAYS IS GIVEN.

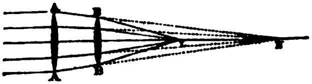
Multiply the length of the principal focus by the focus of the incident rays, and divide the product by the difference between the principal focus and the focus of incident rays, and the quotient will be equal to the conjugate focus.

If the distance of the focus of incident rays is less than the principal focus, the value of the conjugate focus will be positive, and it will lie on the same side of the lens as the focus of incident rays; but if the value of the focus of incident rays is greater than the principal focus, the value of the conjugate focus will be negative, and the focus of refracted rays will lie on the other side of the lens.

763. **Combined lenses.**—If two convex lenses, *A A*, *B B*, are placed near together, as in fig. 425, their combined focus will be shorter than that of either lens used above.

Let f be the length of the principal focus of the lens *A A*, and f' the focus of the lens *B B*, and n the distance between the two lenses and f'', the distance of the combined focus from the second lens; then,

425



$$f' = \frac{f' (f-n)}{f+f'-n}$$

If the distance between the lenses is nothing, then,

$$f'' = \frac{f + f'}{f + f'} =$$ the focus of parallel rays.

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762. What is the rule for determining the principal focus of a lens? What is the rule for the conjugate focus? When is the conjugate focus on the same side of the lens as the focus of incident rays? When on the opposite side? 763. What is the effect of combining two lenses? How is the principal focus of a combination of lenses determined?

764. **Oblique pencils**, when transmitted through lenses, have their foci in secondary axes, and their foci are determined by the same rules as the foci of direct pencils in the principal axis.

It has been shown, in section 756, that a ray of light transmitted through a prism in a direction parallel to its base, suffers the least deviation possible; hence in every other position the deviation is increased. From this principle it follows that the foci of oblique pencils transmitted through lenses will be somewhat shorter than the foci of direct pencils. This fact requires consideration in the formation of the images of large objects. (See section 768.)

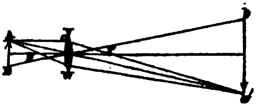
765. **The optical centre of a lens** is a point so situated that every ray of light passing through it will undergo equal and opposite refraction on entering and leaving the lens.

All rays of light passing through the optical centre emerge from the lens parallel to the incident rays. The position, form and foci, of all pencils of light passing through a lens are determined by their relation to some line, or secondary axis, passing through the optical centre of the lens, whether any ray of light from the radiant point actually passes through that centre or not. The optical centre of an equi-lateral double convex, or double concave lens, is at the centre of the lens. The optical centre of a plano convex, or plano concave lens, is at the centre of the curved surface.

766. **Images formed by lenses.**—If an object is placed before a convex lens at a greater distance than the principal focus, an image of the object will be formed on the other side of the lens.

If from the extremities of the object *A B*, fig. 426, the secondary axes, *A a*, *B b*, are drawn through the optical centre of the lens, the image will be formed between these axes prolonged, at a distance equal to the conjugate focus of the lens, estimated separately for every point of the object. If the object is placed beyond the principal focus, and at less than twice this distance, the image will be more distant

426



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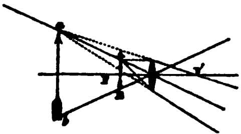
764. Where are the foci of oblique pencils found? What effect is produced upon the foci of pencils of light by transmitting them obliquely through a lens? What are secondary axes? Where is the optical centre of a double convex or double concave lens of equal curvature on both sides? Where is the optical centre of a plano convex or plano concave lens? 766. On which side of a lens are real images formed? Explain the formation of images by a convex lens.

and larger than the object. If the object recedes from the lens, the image will approach it. When the object is removed from the lens, more than twice the principal focus, the image will be smaller than the object, and it will gradually approach the lens, and diminish in size as the object recedes. The image can never approach nearer to the lens than the principal focus. The linear magnitude of the image as compared with the object will be proportional to their respective distances from the lens.

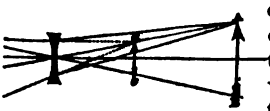
If the object is placed nearer to the lens than the principal focus, as *A B*, fig. 427, the rays will diverge after passing the lens, and a ***virtual image, a b***, will be formed on the same side of the lens as the object. The virtual image formed by a convex lens is always larger than the object.

427



If an object, *A B*, fig. 428, is placed before a concave lens, the rays from every point of the object will diverge after refraction more than they did before entering the lens; consequently a ***virtual image***, smaller than the object, will be formed on the same side of the lens. The size of the virtual image will be in proportion to its distance from the lens.

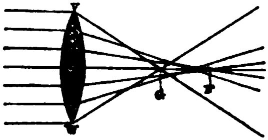
428



767. **Spherical aberration of lenses.**—It has been assumed that spherical lenses bring rays of light issuing from a point to a sensible focus. For many purposes, however, greater accuracy is required, and it becomes necessary to consider the imperfections of spherical lenses.

If the diameter of the lens *V W*, fig. 429, is large in proportion to its radius of curvature, rays of parallel light will not be brought to an accurate focus, but while the central rays cross the axis at *F*, the extreme rays will intersect the axis at *G*, and intermediate rays will intersect the axis at every possible point between *F* and *G*. The distance, *F G*, is called the ***longitudinal spherical aberration*** of the lens.

429



When is the image smaller, and when larger than the object? When is a virtual image formed by a concave lens? Is a virtual image formed by a convex lens larger, or smaller than the object? What kind of images are formed by concave lenses? On what does the size of the virtual image depend? 767. What is meant by spherical aberration of lenses?

For lenses of small aperture, the aberration is in proportion to the square of the angular aperture of the lens, but for lenses of larger aperture, the aberration increases more rapidly than would be required by this proportion. If the length of the principal focus be taken as unity, the longitudinal aberration for lenses of different angular apertures will be as follows:

For 15° the aberration will be 0·025,
" 22° " " " " 0·062,
" 30° " " " " 0·150,
" 45° " " " " 0·375.

This effect of spherical lenses causes images to be formed at every point between *F* and *G*, the rays going from each image, more or less interfering with the distinctness of all the others.

The amount of spherical aberration depends also on the form and position of lenses. If n = index of refraction, r = the radius of the anterior surface, and R = the radius of the posterior surface, then for parallel rays, the form of least aberration will be expressed by the following equation.

$$\frac{r}{R} = \frac{4 + n - 2n^2}{2n^2 + n}$$

If $n = 1\frac{1}{2}$, the form of least aberration will be a lens whose surfaces have their radii in the proportion of 1 to 6, the side of deeper curvature being towards parallel rays. If the spherical aberration of such a lens, in its best position, is taken as unity, the aberration of other lenses will be as follows:

Plano convex with plane surface towards distant objects, 4·2.

Plano convex with convex surface towards distant objects, 1·081.

Plano concave the same as plano convex.

Double convex or double concave with both faces of the same curvature, the aberration will be 1·567.

768. **Aberration of sphericity; distortion of images.**—When a straight object is placed before a lens, the extremities of the object not being in the principal axis, if the images of the extreme points are formed in the secondary axes at the same distance from the optical centre of the lens, as the central portions of the image, the image will not be straight, but formed on a curve, the centre of which is at the optical centre of the lens, as *a′ b′*, fig. 50. But as an object recedes from the lens, the

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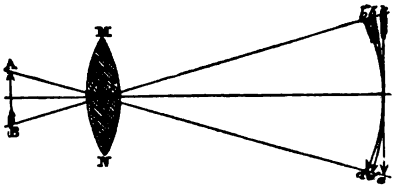
How does the sperical aberration of a lens compare with its angular aperture? What is the form of a lens of least spherical aberration? In what position does a plano convex lens have the least aberration? 768. Explain the various causes which produce distortion of images.

image will approach it, therefore as A and B are more distant from the lens than the centre of the object, the extremities of the image must be nearer than the centre, and instead of a' C b', we shall have the image a'' C b'', described around a centre, somewhere between the lens and the centre of the image. Oblique pencils are also more strongly refracted than pencils which belong to the principal axis; hence this cause must tend to curve the image still more. This curvature, or distortion of images, is called *aberration of sphericity.* For ordinary purposes this imperfection of lenses may be disregarded. The practical method of overcoming these difficulties will be best explained in connection with the description of achromatic lenses.

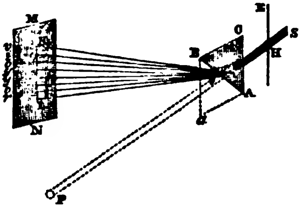
430



CHROMATICS.

769. **Analysis of light.—Spectrum.—Primary colors.**—A beam of sunlight, S H, fig. 431, admitted into a dark chamber, through a small opening in the shutter, E, forms a round white spot, P, upon a screen or any other object upon which it falls. If a triangular prism, B A C, is interposed in its path as shown in the figure, the light will be refracted both on entering and leaving the prism, but instead of forming only a circular white spot on the screen, M N, it will be spread over a considerable space from S to K, called the *solar spectrum*, in which will be seen all the colors of the rainbow. Beginning with the color most refracted, they are *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*. If an opening is made in the screen so as to permit only the rays of a single color to pass, and we attempt to analyze this color by passing it through a second prism, we find it cannot be further decomposed by refraction;

431



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769. Describe the method of analyzing light by a prism. What are the primary colors obtained by this method? What color is most refracted?

hence the colors of the solar spectrum produced by the refraction of a triangular prism are generally called *primary colors.*

770. **Recomposition of light.**—If a second prism, *A B a*, exactly similar to *B A C*, is placed behind the first, but in a reversed position, as shown in the figure, the differently colored rays will be re-united and form white light at *P*, as though no prism had been used.

Moreover, if, instead of the second prism, a double convex lens is so placed as to receive the colored rays and converge them to a focus, a round spot of white light will be again formed in the focus of the lens.

If colored powders are mixed in the proportions that the several colors occupy in the solar spectrum, the color of the compound will be a grayish white. That the resulting color is not pure white is probably owing to the fact that we cannot procure artificial colors that will accurately represent the colors of the solar spectrum.

771. **Analysis of colors by absorption.**—Although the colors of the prismatic spectrum cannot be further divided by refraction, Brewster has shown, that any of the colors may be still further decomposed by transmission through variously colored glass. He thus ascertained that *red*, *yellow*, and *blue* light are found in various proportions in all parts of the spectrum, and that any other color whatever may be formed by suitable combinations of these three. Brewster and other eminent philosophers have hence inferred that there are really only *three primary colors*, *red*, *yellow* and *blue.*

Dr. Young considered red, green and violet, primary colors. According to Herschel, any three colors of the spectrum may be taken as primary, and all other colors may be compounded from them, with the addition of a certain amount of white. The distinction of colors into primary and secondary, should therefore be considered to a certain extent as arbitrary, and as adopted principally for convenience of illustration.

772. **Complementary colors.**—Any two colors which by their union would produce white light, are said to be complementary to each other. If we take away from the solar spectrum any color whatever, we may re-unite all the remaining colors, by means of a double convex lens, or by a second prism, and the

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770. How can several colored rays be so combined as to produce white light? 771. How may light be analyzed by absorption? How many primary colors are recognized by Sir David Brewster?

resulting color will obviously be complementary to the first, because it is just what the first wants to make white light. In this manner it is found that,

Red is	complementary	to	Green.
Violet red	"	"	Yellowish green.
Violet	"	"	Yellow.
Violet blue	"	"	Orange yellow.
Blue	"	"	Orange.
Greenish blue	"	"	Reddish orange.
Black	"	"	White.

The subject of harmony and contrast of colors, will be treated in connection with the phenomena of vision.

773. **Properties of the solar spectrum.**—In the solar spectrum there are found three distinct properties which exist in various degrees of intensity in the differently colored rays. See fig. 434.

(*a*) *Luminous rays.* According to Herschel, Fraunhofer and others, it is found that the maximum illuminating power resides in the yellow rays, and the minimum in the violet.

(*b*) *Calorific, or heating rays.* The position of greatest intensity for the calorific rays varies with the nature of the material of the prism with which the spectrum has been produced. In the spectrum produced by a prism of *crown glass*, the greatest heating power is found in the *pale red.* If a prism filled with *water* is used, the greatest heating power is found connected with the *yellow rays.* If the prism is filled with *alcohol*, the greatest heat is connected with the *orange yellow.* With prisms, formed of highly refracting *gems*, the maximum heating power is found beyond the *red ray.* Flint glass resembles the gems in this respect.

(*c*) *Chemical rays.*—In a great variety of phenomena, solar light acts as a chemical agent. Under the influence of solar light, plants decompose carbonic acid, evolving pure oxygen and most vegetable colors are destroyed; phosphorus is changed to its red or amorphous state, and loses its power of emitting light; chlorine and hydrogen may be safely mixed in the dark, but combine with an explosion when exposed to the sun's light; the green color of plants disappears in the dark, and the nature of the vegetable juices is changed when withdrawn from the

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772. What is meant by complementary colors? Name the several colors which are complementary to each other. 773. What three remarkable properties are found in solar light?

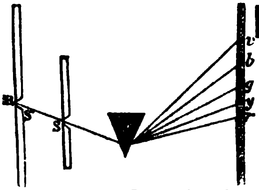
chemical action of light; and the wonderful phenomena of photography depend upon the action of light upon sensitive chemical substances. The maximum chemical effect, produced by solar light, appears to be connected with the violet rays, or with rays between the violet and the blue. Some chemical effect is produced by rays refracted entirely beyond the extreme border of the visible violet rays. The *lavender light* of Herschel results from the concentration of the so-called invisible rays, beyond the border of the violet, where the greatest chemical power resides. A large convex lens gathers these otherwise invisible rays into a faint beam of lavender colored light.

774. **Fraunhofer's dark lines in the solar spectrum.**—In 1802, Dr. Wollaston first discovered the existence of dark lines in the solar spectrum, but the discovery excited no special attention, and was applied to no practical purpose.

Unacquainted with Wollaston's observations, the late celebrated Fraunhofer, of Munich, re-discovered the dark lines of the spectrum, now distinguished as *Fraunhofer's dark lines.* Viewing through a telescope the spectrum formed from a narrow line of solar light, by the finest prisms of flint glass, he noticed that its surface was crossed by dark lines of various breadths. None of these lines coincide with the boundaries of the colored spaces. From the distinctness and ease with which they may be found and identified, seven of these lines have been distinguished by Fraunhofer by the letters B, C, D, E, F, G, H. Numerous other lines—varying from 600 to 2,000 in number, according to the power of the telescope with which they are viewed—have since been counted in the solar spectrum.

To view these lines with the naked eye, a ray of sunlight is admitted into a dark chamber through narrow openings in two screens, one placed behind the other, as shown in fig. 432, and is then re-

432



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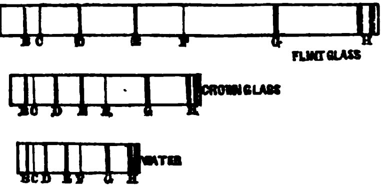

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774. What are Fraunhofer's dark lines? How may they be observed? In what respect are their positions the same in spectra obtained by prisms of different materials? How do they differ?

fracted by a prism of the purest flint glass. The lines, or some of them, will then be seen on the screen. The positions of these lines in the colored spaces of the spectrum is perfectly definite, but their distances from each other vary with the substance of which the prism is formed. Fig. 433 shows the arrangement of the dark lines in the spectrum, formed by prisms of flint and crown glass, and also by a prism filled with water. These dark lines answer the important purpose of landmarks for determining the indices of refraction for various substances. The exact limits of the several colors in the spectrum are not well defined, but the dark lines establish definite points from which the practical optician estimates the refractive power of any medium, and also the comparative refrangibility of the differently colored rays in which the dark lines occupy fixed positions.

In the spectrum produced by the light of the sun, whether reflected by the moon or planets, or from the clouds or any terrestrial object, the position of the dark lines is invariable. But the light of the stars differs from that of the sun, and the light of one star differs from other stars in regard to the number and position of the dark lines in the spectrum. Electrical light, and the light of flames produced by any burning body whatever, give bright lines instead of the dark lines in the spectrum formed by solar or stellar light.

The relation of the dark lines to the colors of the spectrum is shown in fig. 434. *B* lies in the red portion near the end; *C* is farther advanced in the red; *D* in the orange is a strong double line easily recognized; *E* in the green; *F* in the blue; *G* in the indigo; and *H* in the violet. Besides these, there are also others very remarkable; thus *b* is a triple line in the green, between *E* and *F*, consisting of three strong lines, of which two are nearer each other than the third; *A* is in the extreme border of the red, and *a* is a band of delicate lines between *A* and *B*.

775. Intensity of luminous, calorific, and chemical rays.—

434

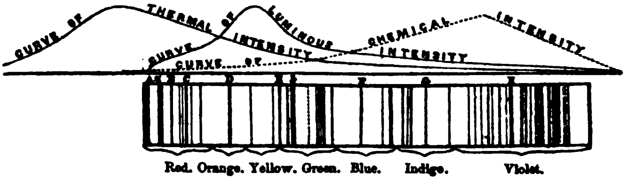
CURVE OF THERMAL INTENSITY
CURVE OF LUMINOUS INTENSITY
CURVE OF CHEMICAL INTENSITY
A a B C D E b F G H
Red. Orange. Yellow. Green. Blue. Indigo. Violet.

Fig. 434 also shows how the intensity of the luminous, calorific, and

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How does the light of the stars differ from sunlight? What remarkable peculiarity in the light of flames and in electrical light?

chemical rays, varies in different parts of the spectrum. The greatest illuminating power resides in the yellow part of the spectrum. The heating power is almost entirely absent in the violet and the blue, where the chemical agency is greatest, and it is greatest beyond the red, and extends a considerable distance, where no illuminating or chemical power is ordinarily manifest. The relative positions of the maximum illuminating, chemical, and heating powers of the solar spectrum, vary somewhat with the nature of the substance composing the prism with which the spectrum has been produced.

776. **Refraction and dispersion of the solar spectrum.—Kalychromatics.**—If a glass tube, retort neck, drinking glass, or any similar instrument of glass be held in the path of the colored rays from a triangular prism in a dark chamber, a beautiful system of colored rings will be formed, varying their form, position and color, with every change in the position or form of the glass interposed. This experiment exhibits, in the most surprising and agreeable manner, the wonderful resources of color contained in the solar beam. Language fails to express the exquisite and wonderful beauty of this simple experiment, involving only the refraction and dispersion of the solar spectrum. *Kalycromatics*, (from the Greek for beautiful colors,) has been suggested as a word to distinguish these phenomena.

777. **Chromatic aberration.**—When rays of ordinary white light are refracted by a lens of any form, consisting of a single transparent substance like glass, or a transparent gem, the rays are each acted upon as by a prism, and dispersed into all the colors of the solar spectrum. This effect is shown by fig. 435, where *V* is the focus of the violet rays which are most refracted, and *R* is the focus of red rays which are least refracted. A violet image is formed at *V*, and a red image at *R*, and as the other colors are situated between the violet and the red, all the space between *V* and *R*, is occupied by other images of intermediate colors. If an image of a point or line is formed at *V*, its color will be violet, but it

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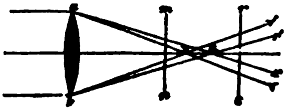

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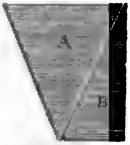
775. How does the intensity of the luminous calorific and chemical rays differ in different parts of the spectrum? 776. How can magnificent exhibitions of colored light be produced in connection with the solar spectrum? 777. What is chromatic aberration?

will be surrounded by fringes composed of all the colors of the spectrum, the outer border of the fringe being red. This defect of all single lenses, formed of whatever substance, is called *chromatic aberration.*

778. **Achromatism.**—We have seen, section 774, fig. 433, that the spectrum formed by flint glass is nearly twice as long as that formed by crown glass. If therefore we take a prism of crown glass, *A*, fig. 436, and another prism of flint glass, *B*, having a refractive angle so much smaller than the refractive angle of *A*, that the solar spectrum formed by it, will exactly equal in extent the spectrum formed by the first prism, we may place the two prsims in opposition, as shown in the figure, and the colored rays separated by transmission through one prism, will be exactly reunited by the other. The light transmitted through the two prisms, thus placed, will therefore be of the same color as before transmission. But while the color of the transmitted light is unaltered, its direction will be changed by about one-half the refractive power of the prism *A;* for while the prism, *B*, has neutralized all the dispersion of color produced by *A*, it has neutralized only about half of its refractive power.

436



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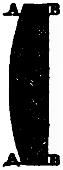

Applying these principles to lenses, a double convex lens of crown glass, *A A*, fig. 437, may be united with a plano concave lens of flint glass, *B B*, having a focus about double the focus of the convex lens. These two lenses will act like the prisms in the preceding figure. The concave lens of flint glass will correct the chromatic aberration of the double convex lens of crown glass, and leave about one-half of the refractive power of the convex lens as the effective refracting power of the compound lens. An achromatic lens, formed of a double convex lens of crown glass, equally convex on both sides, joined with a plano concave lens of flint glass, having its concave side ground to fit one side of the double convex lens, will have the focus of a simple plano convex lens, with its convexity equal to one side of the double convex lens.* The forms of

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* As there is considerable difference in the refractive and dispersive powers of different specimens of both flint and crown glass, these results are to be regarded only as illustrations of the *principle* of achromatism, the proportions of the several curves varying for different kinds of glass.

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778. What is an achromatic prism? Explain the structure of an achromatic lens.

the convex lens of crown glass and the concave lens of flint glass, may be varied to any extent, provided their separate foci are inversely as the dispersive power of the substance of which each lens is made.

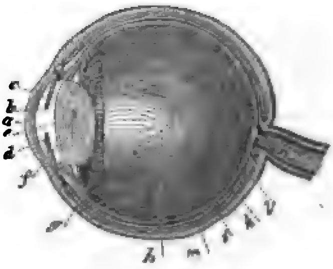
VISION.

779. **Structure of the human eye.**—The human eye is the most perfect of all optical instruments. By means of this organ, stimulated by the light reflected or refracted from external objects, we recognize their presence, nearness, color and form. Some knowledge of the structure and action of the eye is essential to a proper understanding of the uses of other optical instruments.

The eye, situated in its bony cavity called the orbit, is maintained in its position by the optic nerve and its sheath, by muscles which serve to move it or hold it steady in any required position, and by the delicate membrane called the conjunctiva, which covers its anterior surface and lines the eyelids. The eyelids serve to protect the organ from external injuries, and also to shut out light which might otherwise be troublesome or injurious by its excess, or too long continued action.

Fig. 488 shows a horizontal section of the eye, the lower part of the figure representing the side of the eye towards the nose. The globe, or ball of the eye, is nearly spherical, though the anterior portion is more convex than the other portions, as shown in the figure.

438



The principal portions of the eye which require consideration, are the sclerotic coat, the cornea, the choroid coat, the retina and optic nerve, the iris, the pupil, the crystalline lens, the aqueous humor, the vitreous humor, and the hyaloid membrane.

The *sclerotic* coat, *i*, is a strong opaque structure, composed of bundles of strong white fibres, interlacing each other in all directions. This membrane covers about four-fifths of the eyeball, and more than any other structure, serves to preserve the glob-

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779. What is the organ of vision? Describe the structure of the eye.

ular form of eye. It has a posterior sieve-like opening, for the transmission of the fibres of the optic nerve, *n;* anteriorly, a transparent membrane called the *cornea*, *a*, is set into a groove in the sclerotic coat, as a watch crystal is set in the case, but these two membranes are so firmly united that they are separated only with considerable difficulty. The cornea is more convex than the sclerotic coat.

The *choroid* coat, *k*, is a strong vascular membrane, lining the sclerotic coat, and covered internally by a dark pigment, the *pigmentum nigrum*, which prevents any reflection of light from the internal parts of the eye.

The third, or inner membrane of the eye, is the *retina*, *m*, which is merely an expansion of the optic nerve, *n*, uniting it to the brain. It is on this delicate lining membrane, (the retina,) that the images of external objects are formed.

The *iris*, *d*, which forms the colored part of the eye, is a dark annular curtain or diaphragm, adherent at its outer margin, with a central opening which, in man, is circular; in cats and the feline tribe generally it is elongated vertically; in the ox and other ruminating animals, in a horizontal direction. The central opening of the iris, *e*, which allows light to penetrate the eye, is called the pupil. It varies from one-eighth to one-quarter of an inch in diameter. In a strong light the pupil contracts, but where the light is diminished it expands.

Every one knows the sensation produced by entering a house after spending hours in the open air exposed to the light of the sun reflected from snow. In this case the pupil becomes so contracted, and the eye so accustomed to a strong light, that objects within doors are almost invisible until the pupil expands and the eye recovers its sensitiveness in ordinary light. The movements of the iris are involuntary.

The pupil of the owl is so very large that it sees distinctly at night, while in the day-time the pupil cannot contract enough to protect the eye from the blinding effect of the solar rays, and hence the owl is nearly blind by day.

The *crystalline lens*, *f*, fig. 438, is a transparent body, placed behid the iris and very near to it; it is enveloped in a transparent membrane or capsule, which adheres by its borders to the ciliary process, *g*. The posterior surface of the crystalline lens, is more convex than the anterior. The crystalline lens is made

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What is the use of the iris? How does the crystalline lens act upon light?

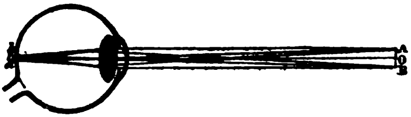
up of serrated fibres, arranged in layers which increase in density from the circumference to the centre of the lens.

Aqueous humor.—The space between the cornea and the crystalline lens is filled with a transparent liquid called the aqueous humor. The iris divides this space into two chambers, the anterior chamber, *b*, between the cornea and the iris, and the posterior chamber, *c*, between the iris and the crystalline lens. These two chambers communicate freely with each other through the pupil, *e*. The free edge of the iris floats in the aqueous humor.

Vitreous humor.—The posterior compartment of the eye, *h*, behind the crystalline lens, constitutes by far the larger part of the internal cavity of this organ, and is filled with a transparent gelatinous fluid, inclosed in exceedingly delicate cellular tissue, which is condensed externally, and forms a delicate *hyaloid membrane*, everywhere covering the retina and the posterior surface of the crystalline lens. The vitreous humor, inclosed in its cellular tissue, and enveloped by the hyaloid membrane, is called the *vitreous body*.

780. **Action of the eye upon light.**—The eye may be compared to a dark chamber, the pupil being the opening to admit the light, the crystalline lens being a converging lens to collect the light, and the retina a screen upon which is spread out the image of external objects. The effect is the same as when a double convex lens forms, at its conjugate focus, an image of any object placed in the other focus.

439



Let *A B*, fig. 439, be an object placed before the eye, and consider that rays are emitted from any point, as *A*, in all directions; only those rays which are directed towards the pupil can penetrate the eye, or contribute to the phenomena of vision. The rays, on entering the aqueous humor, are refracted towards the axis, *O o*, drawn through the optical centre of the crystalline lens; but on entering the lens, which is more dense than the aqueous humor, they are still further refracted, and undergoing yet another refraction on leaving the crystalline lens, they converge towards a point, *a*, where they form an image of the point, *A*. The rays of light emitted from *B*, form its image in the point *b*, and in the same manner every part of the ob-

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780. In what part of the eye, and how are images of external objects formed?

ject *A B*, is delineated in the very small image *a b*, which is a real image, inverted, and formed exactly upon the retina.

781. **Inversion of the image formed in the eye.**—To prove that the image formed in the eye is really inverted, take the eye of an ox, cut away the posterior part of the sclerotic and choroid coats; fix the eye thus prepared in an opening in the shutter of a dark chamber, and look at it with the aid of a magnifying glass, when external objects will be seen beautifully delineated in an inverted position, on the retina of the posterior part of the eye.

Philosophers and physiologists have proposed various theories to explain how we come to perceive objects erect, when their images in the eye are actually inverted. The most rational of these theories are the two following: 1st. That we judge of the relative position of objects, or of different parts of the same object, by the direction in which the rays come to the eye, the mind tracing them back from the eye towards the object. 2d. That the image formed on the retina, gives correct ideas of the relation of external objects to each other, up and down being, in reference to impressions on the retina or brain, merely the relative directions of the sky and earth; and we see all bodies, including our own persons, occupying the same relations to these fixed directions as our other senses demonstrate that they really occupy.

782. **Optic axis.—Optic angle.**—The principal axis of the eye, called the *optic axis*, is its axis of figure, or the right line passing through the eye in such a position that the eye is symmetrical on all sides of it. In a well formed eye this is a right line, passing through the centre of the cornea, the centre of the pupil and the centre of the crystalline lens, as *O o*, fig. 439. The lines *A a*, *B b*, which are sensibly right lines, are secondary axes. Objects are seen most distinctly in the principal optic axis.

When both eyes are directed towards the same object, the angle formed by lines drawn from the two eyes to the object, is called the *optic angle*, or the *binocular parallax*.

To appreciate this difference of direction, look at two objects that are situated in a line with one eye, the other being closed; then, without moving the head, look at the same objects with the other eye, and the objects will not both appear in the same line, but will

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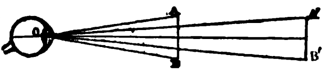
781. Why is the image formed upon the retina inverted? How can an inverted image on the retina give to the mind a correct idea of the relation and position of external objects? 782. What is meant by the optic axis? What is binocular parallax?

seem suddenly to change their positions. By such experiments it will readily be found that some persons see principally with the right, and others chiefly with the left eye, when both eyes are open. Others will find that a part of the time the direction of objects is determined by one eye, and part of the time by the other.

783. **Visual angle.**—The angle formed between two lines drawn from the eye to the two extremities of an object, is called the *visual* angle, as *A O B*, fig. 440. If the object is removed to twice the distance, the visual angle *A' O B'* will be only one-half as great as *A O B*, and the breadth of the image formed on the retina will be proportionally decreased.

440



The apparent linear magnitude of an object is in inverse proportion to its distance from the eye, or in direct proportion to the visual angle. The *apparent superficial magnitude* is always the square of the apparent linear magnitude, and is in inverse proportion to the square of the distance.

784. **The brightness of the ocular image** of any object will be in direct proportion to the intensity of the light emanating from each point in the object.

The amount of light received by the eye from any point in the object, or from the entire object, will be inversely as the square of the distance, and directly as the intensity of the light from each point. (732.) But the superficial magnitude of the image will diminish as the square of the distance increases; hence, *the apparent brightness of the image will remain constant, whatever may be the distance of the object.*

As the object recedes from the eye, the size of the image formed on the retina diminishes, the details of the various parts become crowded together, and only the bolder outlines occupy sufficient space to make a sensible impression, or to be clearly discerned.

785. **Conditions of distinct vision.**—It may be stated in general, that two conditions are essential to distinct vision. 1st. That an object should be situated at such a distance as to form on the retina an image of some appreciable magnitude. 2d.

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783. What is the visual angle? How is the apparent linear magnitude of an object determined? How is the apparent superficial magnitude of an object determined? 784. On what does the brightness of an image depend? Explain why the apparent brightness of an image is the same whether the object is near or remote.

That the object shall be sufficiently illuminated to produce a distinct impression upon the retina.

The distance at which an object can be seen varies with the color of the object, and the amount of illumination. A white object illuminated by the light of the sun can be seen at a distance of 17,250 times its own diameter. A red object illuminated by the direct light of the sun can be seen only about half as far as though it were white, and blue at a distance somewhat less. Objects illuminated by ordinary day-light can be seen only about half as great a distance as when illuminated by the direct rays of the sun. The smallest visual angle under which an object can be seen with the naked eye, is estimated at twelve seconds. All these calculations will vary for different eyes. Persons having dark colored eyes can generally see much farther than those who have light colored eyes. Those whose eyes are trained to view distant objects, as sailors and surveyors, will see objects that are far too distant to be seen by the eyes of inexperienced persons.

786. **Background.**—The distance at which the outline of any object can be distinguished, depends very much upon the color of adjacent objects, or of the background on which the object appears projected. Objects are most distinctly seen when the color of adjacent objects, or the background, presents a strong contrast to the colors of the object we wish to see.

Colored signals.—For signal flags used at sea, the colors *red, yellow, blue* and *white* are employed, because they are readily distinguished, and are easily seen, with the water or the sky for a background. For railroad signals, the colors *red, white* and *black* are mostly used.

787. **Sufficiency of illumination.**—It is not enough for distinct vision, that a well defined image of the object shall be formed on the retina. This image must be sufficiently illuminated to affect the senses, and at the same time not so intensely illuminated as to overpower the organ. An image may be so faint as to produce no sensation, or it may be so intensely brilliant as to dazzle the eye, destroy the distinctness of vision, and produce absolute pain.

When we look at the meridian sun, its light is so brilliant as to

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785. What are the conditions of distinct vision? At what distance can an object be seen under the most favorable circumstances? What color can be distinguished at the greatest distance? What is the smallest visual angle under which an object can be seen? 786. What colors are usually used for signals? 787. Explain the effect of different kinds of illumination upon objects.

overpower the eye and render it impossible even to see distinctly the solar disc, but if a sufficient stratum of vapor, or a colored or smoked glass is interposed, we see a well-defined image of the sun.

Many stars are so distant that the rays which enter the pupil, when converged to a point on the retina, produce no appreciable sensation, but when the amount of light from the same stars falling upon a large lens is concentrated upon the retina, it produces sensation, and the stars become visible.

On passing from a dark room to one brilliantly illuminated, or on going out into the open air at night from a well-illuminated room, the sensations experienced are owing partly to the contraction and expansion of the iris, as explained in section 779, and also to the fact that the *sensibility* of the retina is diminished by long exposure to intense light, and increased by remaining a long time in feeble light.

788. **Distance of distinct vision.**—Though the human eye is capable of seeing objects at both great and small distances, most persons, when they wish to see the minute structure of an object clearly, instinctively place it at a distance of from six to ten inches from the eye. This point, called the *limit of distinct vision*, sometimes varies for the two eyes of the same person. Persons who see objects at very short distances are called *near-sighted*, while those who see objects distinctly only at greater distances, are said to be *long-sighted.*

789. **Visual rays nearly parallel.**—When we consider that the diameter of the pupil, when the eye is adjusted for viewing near objects, is only about one-tenth of an inch, if we take the limit of distinct vision at six inches, it will be found that the cone of rays entering the eye, from any single point, is included within an angle of one degree. If we take the limit of distinct vision at ten inches, the angular divergence of the cone of rays entering the eye from a single point will be little more than half a degree. In either case, therefore, the rays differ but slightly from parallel rays. For all objects more remote, the rays may properly be considered as parallel. Distinct vision is therefore obtained only by rays that are *sensibly parallel* or *very slightly divergent.*

790. **Adaptation of the eye to different distances.**—Although there is a definite distance at which minute objects are most dis-

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How is the sensitiveness of the eye affected by a strong light? 788. What is the limit of most distinct vision? When are persons said to be near-sighted? When long-sighted? 789. By what rays is distinct vision obtained?

tinctly seen, the eye has a wonderful facility of adapting itself to viewing objects at different distances.

Let two similar objects be placed, one three feet from the eye and the other at a distance of six feet. If the eye is fixed steadily upon the nearer object for a few moments, it will be distinctly seen, while the more remote object will appear indistinct, but if the eye is steadily fixed upon the the remote object, that object will soon be clearly seen, and the nearer object will appear indistinct. We thus see that either the converging power of the eye is subject to rapid variation, or that the distance of the crystalline lens from the retina is changeable. The means by which the eye thus rapidly adapts itself to viewing objects at different distances, have not been satisfactorily determined.

791. **Appreciation of distance and magnitude—aerial perspective.**—The appreciation of the distance and magnitude of objects is entirely a matter of unconscious training, or education, and depends upon a variety of circumstances, as the visual angle, optic angle, comparison with familiar objects, and distinctness or dimness of the image, caused by intervening air or vapor.

When the magnitude of an object is known, as the height of a man, a house, or a tree, the visual angle under which it is seen enables us to appreciate its distance. If its magnitude is unknown, we judge of its size by comparing it with other familiar objects situated at the same distance.

In viewing a range of buildings, or a row of trees, the visual angle decreases as the distance increases, and the objects decrease in apparent size in the same proportion, but the habit of viewing the houses or trees, and their known altitude, causes us to correct the impression produced by the visual angle, so that they do not appear to decrease in size as fast as their distance increases.

Thus, when distant mountains are seen under a very small visual angle, occupying but a small space in the field of view, being accustomed to aerial perspective, we unconsciously restore to some extent their real magnitude.

The optic angle, or binocular parallax, is an essential element in appreciating distances. This angle increases or diminishes inversely as the distance; the movement of the eyes required, to cause the optic axes of the two eyes to converge upon any object which we are viewing, gives us an idea of its distance. It is only by habit that

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790. Can the eye distinguish distant and near objects with equal clearness at the same time? What changes are probably required to adapt the eye to different distances? 791. How does the eye judge of distances?

we appreciate the relation between the distance of an object and the corresponding movement of the eyes, required to direct both eyes upon it.

When persons blind from birth have obtained their sight by an operation for cataract, all objects appear to them to be situated at the same distance, until experience enables them to judge correctly of distances. Infants plainly have no notion of relative distances and magnitudes, and vainly grasp at vacancy.

792. **Single vision with two eyes.**—When both eyes are directed to the same object, similar images are produced in both eyes, and the inquiry is most natural why all objects thus seen do not appear double? Passing by much learning bestowed on this subject, the simplest and most satisfactory explanation of the phenomenon is deduced from the anatomical structure of the optic nerves, and their relations to each other, and to the brain. The eyes may be compared to two branches issuing from a single root, of which every minute portion bifurcates, so as to send a twig to each eye. (Müller.) The optic nerve from the right lobe of the brain sends a portion of its fibres to each eye, and also sends some branches across and backward to the left lobe of the brain. A portion of the optic nerve from the right eye, instead of proceeding to the brain, curves around and enters the optic nerve and the retina of the left eye. In the same manner the optic nerve arising from the left lobe of the brain is connected with the right eye, and sends branches also to the left eye.

Branches of the same nerve fibres which go to the external side of the retina of one eye, go to the internal side of the retina in the other eye.

It is thus that a perfect sympathy and correspondence is established between similar parts of both eyes. Hence whatever object is observed, if the optic axes of both eyes are directed towards it, the image is formed on corresponding portions of the retina in both eyes, and the mind receives the impression of a single object; but the impression is more vivid than if the same object were seen with only one eye. So perfect is this sympathy between the two eyes, that if one eye only is exposed to a strong light, the pupils of both eyes contract. If one eye is diseased and protected from the light, it suffers pain from light entering only the sound eye.

793. **Double vision.**—If both eyes are fixed steadily upon one object, any other object which may be seen at the same time will appear double.

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792. Why do not objects seen with two eyes appear double?

Fix both eyes steadily upon the flame of a lamp or candle, and a finger held between the eyes and the light will appear double.

Drunken persons, or persons about falling asleep, often see objects double, owing to the inability to direct both eyes steadily upon the same object. The same phenomena may occur when, from any cause, the nerves which control the eye become diseased.

794. **Near-sightedness.**—Many persons are unable to see minute objects distinctly unless they are placed within three or four inches of the eye. Such persons are often unable to see ordinary objects distinctly in a large room or across the street; they are therefore said to be near-sighted. (788.) This defect is owing to a too great convergent power, the eye bringing parallel or slightly divergent rays to a focus before they reach the retina.

To secure distinct vision in such cases, it is necessary to bring the object so near the eye as to render the rays entering the eye, considerably divergent, when the image will be formed on the retina. The same object may be accomplished by placing a concave lens before the eye, when the rays from distant objects will be rendered divergent, and the strong convergent power of the eye will form the image on the retina. Concave lenses for near-sighted persons should be such as have a focus a little longer than the distance at which they see objects most distinctly.

795. **Long-sightedness** commonly occurs in old people, when the eye becomes flattened by diminution of its fluids, or some structural change in the crystalline lens occurs, by which its convergent power is diminished. In such cases the image is formed behind the retina, and vision is most distinct when the object, as a book when reading, is held at a considerable distance from the eyes, so as to allow the image to be formed on the retina.

This defect of the eyes, when not accompanied by disease, may be entirely remedied by using convex glasses, which make up for the diminished converging power of the eyes, and bring the rays to such a condition, that the eye is enabled to bring the light from near objects to a distinct focus upon the retina. In such cases, however, the power of accommodating the eye to different distances is often not as great as in younger persons; hence many people in advanced life find it necessary to use one set of glasses for near, and another for distant objects.

796. **Duration of the impression upon the retina.**—Every one

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793. How can we see objects double? Why do drunken persons often see objects double? 794. What kind of glasses are most useful to near-sighted persons?

knows that a lighted stick whirled rapidly around a circle appears like a ring of fire. The rapidity of revolution required to produce this impression is one-third of a second in a dark room, and one-sixth of a second by daylight.

When a meteor darts across the heavens, it appears to leave a luminous track behind it, because the impression produced upon the retina remains after the meteor has passed a considerable distance on its way. The zigzag course of the lightning appears, for the same reason, as a continuous track.

Winking does not interfere with distinct vision, because the continuance of the impression of external objects on the retina, preserves the sense of continuous vision.

797. **Optical toys.—Thaumatrope.**—A great number of optical toys and pyrotechnic exhibitions owe their effect to the continuance of the impression upon the retina, when the object has changed its place.

If a horse is painted on one side of a card and a rider on the other side, the rapid revolution of the card causes the rider to appear seated on the horse. In the same manner, if any object which takes a variety of positions in moving is painted in successive positions, at equal distances on a revolving wheel, so arranged that one only of the figures shall be seen at a time, the object is seen performing all the motions of real life. In this manner a horse may be made to appear leaping a gate, or boys playing at leap-frog. These toys are called *thaumatropes*. Other toys called *phenakistoscopes* and *phantascopes*, are variations of the same thing, combined with mirrors and other ingenious arrangements on the same principle.

798. **Time required to produce visual impressions.**—If an object moves with sufficient velocity, it is entirely invisible, its image upon the retina not remaining long enough to produce any impression. This is the case with a cannon ball or rifle ball, viewed at right angles to the direction of its flight. But if the projectile is going from us, or coming towards us, it preserves the same direction long enough to allow of an impression. Motions describing less than one minute of arc in a second of time are not appreciable to us. Hence we do not see the movements of the hour hand of a clock, or of the heavenly bodies.

799. **Appreciation of colors.—Color blindness.**—The power of the eye to distinguish colors, varies greatly in different per-

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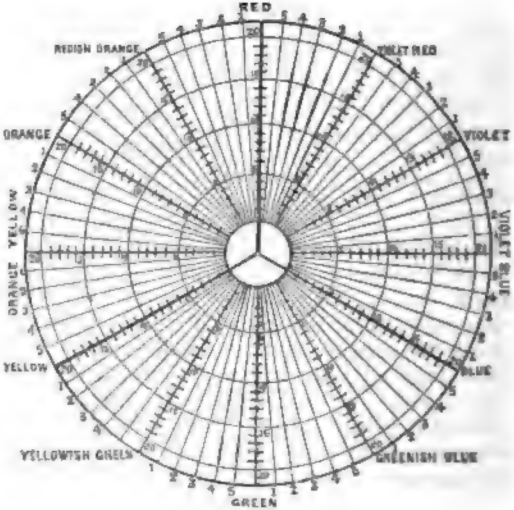
795. Explain the cause of long-sightedness? What glasses do such persons require? 796. How can it be shown that the impression of light is not instantly perceived by the eye? 797. What is the thaumatrope? 798. What is the time of a visual impression?

sons. Some eyes fail entirely in this particular, while in every other respect they are perfect. Such eyes are said to be color blind. Some confound certain colors, as red and green, while they distinguish others, or while they recognize all the colors of the spectrum, they cannot appreciate delicate shades of the same color.

Colors are greatly modified by proper contrast with other colors. Thus the complementary colors mutually enhance, while those not complementary, diminish each other's beauty when contrasted. The sensibility of the eye is much diminished by long inspection of any color, and its power of perceiving the complementary color is proportionally increased. This principle is the key to harmony of colors in nature and art, and serves to explain the modification of color by contrast, and proximity of two or more colors.

800. **Chevreul's classification of colors, and chromatic diagram.**—The chromatic diagram, of Chevreul, fig. 441, greatly facilitates the study of complementary colors, and the modifications produced by their mutual proximity.

441



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799. What is color blindness? How are colors modified by mutual proximity? How is sensibility of the eye affected by protracted observation of a single color? 800. Describe the chromatic diagram.

Three radii of a circle represent Brewster's three cardinal colors, red, yellow and blue; between these are placed orange, green and violet. Between these six colors are placed reddish orange, orange yellow, yellowish green, greenish blue, violet blue, and violet red. We thus obtain twelve principal colors, each of which may be again divided into five scales or hues, which gradually approach the succeeding color.

We thus have the circumference of the circle, which represents the prismatic spectrum, divided into sixty scales of pure colors. Each radius representing a scale of colors is divided into twenty *tones*, to represent the intensity of each color in its own scale. The tone of any color may be lowered by the addition of white, when it will remain in the same radius or scale, but take a position at a lower tone, or nearer the centre of the circle. A color modified by black, is called a broken color, but as the color is deeper, the tone is carried towards the circumference of the circle. To represent the modifications produced by black, Chevreul employs a movable quadrant, not easily introduced in our illustration.

When two complementary colors are mixed, their combination produces white, if the colors are pure. The combination of two colors not complementary produces a certain quantity of white, but principally a color which will be found in the diagram intermediate between the two colors, if they are of the same tone, or nearer to the color of deeper tone, when their tones or intensities are different. The complementary color in the diagram is found at the opposite extremity of the diameter of the circle.

This diagram thus explains the effect which two colors produce upon each other by their mutual proximity.

When two colors are placed near each other, each color appears modified as though mixed with a small portion of the complement to the color which is near it.

Examples.—(*a*) Suppose *blue* and *yellow* to be placed side by side; at one extremity of a diameter we read *yellow*, and at the opposite *violet*, hence the proximity of yellow gives to the blue a shade of violet, or makes it approach *violet blue.* In the same manner we find *orange* complementary to *blue*; hence the blue gives a shade of orange to the yellow, or makes it approach *orange yellow.*

(*b*) Let *green* and *yellow* be contiguous, the yellow will receive red, the complement of green, and will become orange yellow,

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How many scales of color in Chevreul's classification? What is meant by tones of color? What are broken colors? How is the tone of any color modified by white? Show by the diagram what color will be produced by mixing any two colors of the same tone. Explain how blue and yellow will be modified when seen together.

while the green will receive from the yellow its complementary violet. A part of the yellow in the green will thus be neutralized, and the green will appear bluer or less yellow, in fact, greenish blue.

801. **The study of colors** upon the principles here laid down is of great importance to the artist and manufacturer, whether in reproducing the beauties of nature, or in architectural decoration; also in weaving, embroidery and costume.

The skillful salesman knows how to enhance the brilliancy or beauty of his goods by artfully contrasting the pieces which he hopes to sell by others having complementary colors. Good taste in dress never violates these principles, regarding with care the complexion of the wearer in contrast to the colors selected. Florid skins can bear dark hues in dress, while delicate complexions are made pallid by heavy colors. A green dress or wreath increases the freshness of a rosy complexion. A crimson dress and scarlet shawl worn together appear mutually dull and heavy, while either, with the contrast of an appropriate shade of green, would be attractive and tasteful. These topics will be found fully considered in 'Chevreul on colors.'

OPTICAL INSTRUMENTS.

802. **Magnifying glasses.**—Single lenses, used for magnifying small objects, occupy an important place in the arts. They are used by watch-makers, jewelers, engravers, and other artisans, whose labors are performed upon minute structures. These instruments occupy a middle place between spectacles and the regular microscope, composed of a variety of parts.

A thorough knowledge of the uses and powers of simple lenses forms the basis of all calculations of the powers and uses of more complex instruments, like the compound microscope and the telescope.

The eye takes no cognizance of real magnitude, which it can only estimate by inference, but notices directly only apparent magnitude, which is determined in all cases by the visual angle under which objects are seen. (791.)

We have seen (789) that it is essential to distinct vision that the rays entering the pupil from any one point of an object should be parallel, or slightly divergent, the distance of most distinct vision being generally from five to ten inches; for near-sighted persons, as

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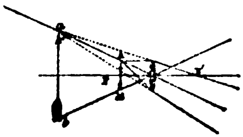
801. To what practical purposes may the study of colors be applied? What is the effect of a green dress or wreath on a rosy complexion? 802. For what purposes are magnifying glasses used? How is apparent magnitude determined?

small, sometimes, as two or three inches, and for eyes enfeebled by age, extending from fifteen even to thirty inches.

803. **The magnifying power of a lens** is found by dividing the limit of distinct vision, (ten inches,) by the principal focus of the lens.

Let *A B*, fig. 442, be an object placed before a convex lens, so much nearer to the lens than the focus, *F*, that the rays, after refraction by the lens, shall be in that state of slight divergence best adapted to produce distinct vision, that is, diverging as though emanating from a point at a distance of ten inches, or the limit of distinct vision; let *a b* represent the virtual image, formed where the refracted rays would meet if extended backward, then *a b* will be as much greater than *A B*, as its distance from the lens is greater than the distance of the object, *A B*, from the lens. The divergence of rays of light entering the small opening of the pupil, from a point ten inches distant, is so small that we may consider them parallel, and then the object, *AB*, will be nearly at *F*, the principal focus of the lens.

442



It is commonly supposed, that inasmuch as the *distance of most distinct vision* differs for different eyes, that therefore the magnifying power of a lens varies for different eyes. If the magnifying power of a lens were always equal to the distance of distinct vision, divided by the principal focus of a lens, it would be variable for different eyes, being two or three times as much for some eyes as for others. But this is not the case. If the eye is placed close to the lens, the distance between the lens and the object will be much less for near-sighted persons than for others, because their eyes are fitted to receive rays of light much more divergent than can be brought to a focus in ordinary eyes. So also persons who see most distinctly at a distance greater than ten inches, require a lens to be placed proportionally more distant from the object. Hence the rule given above, taking ten inches as the distance of most distinct vision, and dividing by the principal, or solar focus of the lens, gives a result for the magnifying power, which is very nearly accurate for every variety of eyes.

The superficial magnifying power is equal to the square of the

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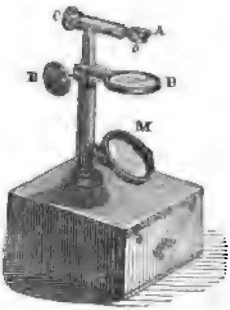
803. How is the magnifying power of a single lens determined? Show how the magnifying power of a lens remains nearly the same for all eyes. How is the superficial magnifing power determined?

linear magnifying power given by the rule stated above; but the linear magnifying power is alone commonly used in scientific treatises.

804. **The simple microscope** acts in the same manner as the single lens or magnifying glass. Instead of a single lens, a doublet or triplet, acting as a single lens, is often used.

Raspail's dissecting microscope, shown in fig. 443, is the most complete simple miscroscope. The magnifying lens, *o*, mounted in a dark cup, *A*, to protect the eye from extraneous light, is fixed in the end of a movable arm which can be rotated on its support, elevated and depressed by the milled head, *E*, or lengthened by turning the milled head, *C*. Below the lens is the stage *B*, which supports the object to be examined. The concave mirror, *M*, can be so adjusted as to illuminate the object by a concentrated pencil of transmitted light.

443



In using this microscope, the eye is placed over the lens *o*, which may be elevated or depressed till the focus is adjusted to give the most distinct view of the object on the stage. Opaque objects are illuminated by a bull's eye lens.

By using lenses of different foci, magnifying powers may be obtained with this instrument, varying from two to one hundred and twenty diameters.

805. **The compound microscope** consists, essentially, of two lenses, so arranged that when an object is placed a little *beyond* the principal focus of the first lens, its image may be formed in the principal focus of the second lens, by which it is viewed as an object is viewed by a common magnifier.

The arrangement of the lenses in the compound microscope is shown in fig. 444, and also the position of the object, and the images both real and virtual.

The object, *s r*, being placed near the first lens, *a b*, called the object-glass, an image, inverted and much enlarged, is formed at *R S*, in the focus of the second lens, *d c*, called the eye-glass. By this lens, the rays are transmitted slightly divergent, and in the exact condition to produce distinct vision when viewed by the eye. The

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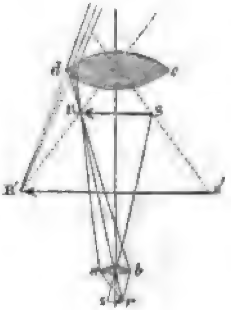
804. Describe Raspail's dissecting microscope. 805. What are the essential parts of a compound microscope? Describe the action of the compound microscope.

rays transmitted through the eye-glass, if traced backward to the distance of distinct vision, form a virtual image at *R′ S′*, much larger than the real image *R S*, formed by the action of the first lens.

444



Such a compound microscope as the one shown in this figure, is subject to chromatic and spherical aberration, and the image viewed by the eye is not straight as shown in the figure, but curved so as to appear convex towards the eye. These imperfections are almost entirely corrected in the *achromatic* compound microscope described in 819.

806. **The telescope** is an instrument constructed for viewing distant objects.

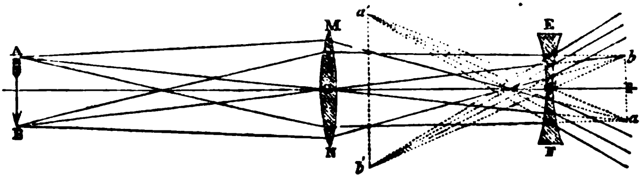
Telescopes are of two kinds. Refracting telescopes are constructed of lenses. Reflecting telescopes contain one or more metallic reflectors.

807. **The telescope used by Galileo** in 1609, is the oldest form of which we have any definite description. The Galilean telescope consists of a convex lens, of long focus, and a concave lens of short focus placed at a distance apart, equal to the difference of their principal foci. The light from distant objects collected by the large surface of the convex field lens, is brought to such a state of divergence by the concave eye-lens as to produce distinct vision in the eye.

The magnifying power of the Galilean telescope is found by dividing the principal focus of the convex lens by the principal focus of the concave lens.

The convex lens, *M N*, fig. 445, tends to form an image of a distant object, *A B*, very near its principal focus, as at *a b*. The concave lens, *E F*, being placed between the convex lens and the image, *a b*,

445



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806. What is a telescope? How do refracting telescopes differ from reflecting telescopes? 807. How is the Galilean telescope constructed? Explain the action of this telescope by reference to fig. 445.

renders the rays which were converging to *a*, slightly divergent, as though emanating from a point, *a'*, at the distance of the distinct vision, about ten inches. The same effect is produced on the rays converging to *b*. The direction of the oblique pencils is changed, and the extremities of the image appear in the secondary axes *a O' b'*, and *b O' b'*, drawn from *a* and *b* through *O'*, the optical centre of the lens *E F*. It is especially to be noticed, that while the rays from any one point in the object are rendered parallel, or slightly divergent by the concave lens, the pencils from the extreme points converge at *O'* much more than at *O*, making the visual angle *a' O' b'*, under which the object is seen by the telescope, much greater than the visual angle *a O b*, under which the object would appear without the telescope.

Since the angle *A O B* is equal to *a O b*, and *a' O' b'* is equal to *a O' b*, the visual angle *a' O' b'* is to the angle *A O B* as *O F* is to *O' F*, and the image *a' b'* appears as much greater than the object as the focus *O F* of the convex lens exceeds the focus *O' F*, of the concave lens.

The opera-glass consists generally of two Galilean telescopes, placed near together, to allow of distinct vision by both eyes.

Night-glasses, used by seamen, are constructed like large opera-glasses. They serve to concentrate a large amount of light in such a condition as to allow of distinct vision, and thus enable the eye to see objects distinctly in the night. They have a low magnifying power.

With the Galilean telescope in all its forms the object appears erect.

808. **The astronomical telescope** may be constructed with a convex lens placed beyond the image formed by the field lens. The second lens then magnifies the image formed by the first lens. The object appears inverted, but this occasions very little inconvenience in astronomical observations.

809. **Eye-pieces** for both microscopes and telescopes consist of two or more lenses, so arranged as to magnify the image formed by the object-glass, with somewhat less spherical and chromatic aberration than if a single lens only were used.

(*a*) *The positive eye-piece*, invented by Ramsden, consists of two plano convex lenses, with their convex surfaces turned towards each other, and placed at such a distance that the object or image

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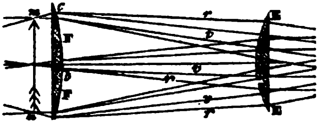
What is the structure of the common opera-glass? What are night glasses? 808. Describe the astronomical telescope. 809. What are eye-pieces? Describe the positive eye-piece. Why does it produce less chromatic aberration than a single lens?

to be viewed by it is seen distinctly when brought very nearly in contact with the first lens. The spherical aberration produced by this eye-piece is only about one-fourth as much as if a single lens were used. The chromatic aberration also is less than with a single lens.

Let *F F*, fig. 446, be the field lens, and *E E* the eye lens of the positive eye-piece. Let *m n* be an image formed by the object glass either of a telescope or a microscope, then each ray from the image on passing the lens *F F* becomes colored, *c v*, *b v*, representing the violet rays, and *c r*, *b r*, representing the red rays. The red rays, which are least refracted by the first lens, fall near the borders of the second lens, where the refractive power is greater than where the more refrangible violet rays fall; hence the second lens tends to correct the chromatic dispersion of the first, and the violet and red rays enter the eye very nearly as though emanating from a common point. This is an important excellence of the positive eye-piece; but a yet more important advantage of this eye-piece is, that the image is less distorted than when only a single lens is used.

446



(*b*) *The negative eye-piece*, which was invented by Huyghens, consists generally of two plano convex lenses, having the convex surfaces of both turned towards the object glass. The two lenses are placed at a distance from each other equal to one-half the sum of their foci. The image is formed between the lenses. This arrangement considerably enlarges the fields of view, and besides diminishing the spherical aberration, the chromatic aberration is less, and is more equalized in all parts of the field than in other eye-pieces.

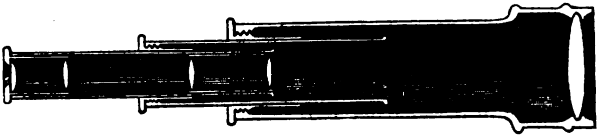
The action of the negative eye-piece will be more fully explained in connection with the compound achromatic microscope. (819.) In the most perfect form of the negative eye-piece, according to Prof. Airy, the first, or field lens, is a meniscus whose radii are as four to eleven, with the convex side toward the object, and an eye-lens having the form of least spherical aberration (767) with the more convex side towards the object.

Describe the negative eye-piece. What is said to be the best form of the negative eye-piece? How many lenses in the terrestrial eye-piece? What is the structure of the common spy-glass?

(*c*) *The terrestrial eye-piece* consists of four lenses, two of them being added solely to produce an erect image.

Fig. 447 shows a section of the common *spy-glass* or *terrestrial telescope,* with the erecting eye-piece. The several tubes which shut one within another, allow the instrument to be reduced to a convenient length when not in use.

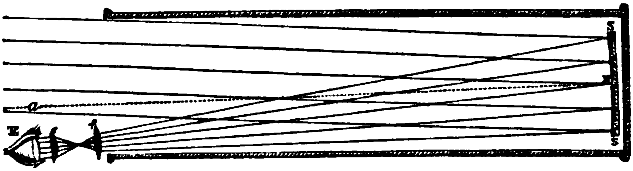
447



810. **Reflecting telescopes** are extensively used for astronomical observations. A variety of forms have been invented by different observers, but in all a metallic speculum is employed to form an image of distant objects, and an eye-piece is used to magnify the image.

811. **Sir William Herschel's telescope,** shown in fig. 448, consists of a speculum, *S S*, set in a tube somewhat larger than the diameter of the speculum, and an eye-piece, *e f*, placed at one side of the open end of the tube. The axis of the speculum, represented by the dotted line *a N*, is so inclined that parallel rays, falling on every part of the speculum, will be reflected, converging to the side of the tube where the eye-piece is placed to receive them. The size of the tube, and the inclination of the axis of the speculum, is so adjusted that the eye of the observer may be placed at *E* without intercepting any part of the light which can fall upon the speculum in such a direction as to be reflected to the eye-piece.

448



Sir William Herschel's great telescope had a speculum four feet in diameter, three and a half inches thick, weighing two thousand one

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811. Describe the structure and action of Herschel's telescope. What were the dimensions of Sir William Herschel's great telescope?

hundred and eighteen pounds. Its focal length was forty feet, and it was set in a sheet-iron tube thirty-nine and a half feet long, and four feet ten inches in diameter. When directed to the fixed stars it would bear a magnifying power of six thousand four hundred and fifty diameters.

This is called the front view telescope, because the observer sits with his back to the object and looks into the front end of the telescope.

812. **Lord Rosse's telescope.**—Ry far the largest reflecting telescope ever constructed was made by the Earl of Rosse. It was commenced in 1842, and was so far completed as to be used for the first time in Feb. 1845.

The great speculum is six feet in diameter, has a focal length of fifty-four feet, and weighs four tons. An additional speculum to be used in the same instrument weighs three and a half tons. The tube is of wood, hooped with iron, and is seven feet in diameter, and fifty-two feet in length.

This telescope has fittings to mount the eye-pieces either for front view, as in Herschel's telescope, or at the side of the telescope, as in the Newtonian form, a small speculum placed at an angle of 45°, reflecting the rays at a right angle through an orifice in the side of the tube, where the eye-piece is placed.

The base of the instrument is supported upon a universal joint; and by chains and windlasses this mammoth telescope is moved with ease, between two lofty walls supporting movable galleries, which enable the observer to follow the instrument in any required position.

The amount of light on any surface being as the square of the diameter, if we reckon the pupil of the human eye at one-tenth of an inch in diameter, this telescope will be seven hundred and twenty times as broad as the pupil, or have an area five hundred and eighteen thousand and four hundred times as great as the unaided eye. If one-half the light is lost by reflection from the mirror, we shall still have two hundred and fifty thousand times as much light as commonly enters the eye. We need not wonder therefore at the marvellous power with which this instrument penetrates the remoter regions of celestial space.

813. **Achromatic telescopes.**—The principle of achromatism has been briefly explained in section 778, where it has been shown that a convex lens of crown glass may be combined with a concave lens of longer focus, made of flint glass, which

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812. What are the dimensions of Rosse's telescope? 813. What forms of lenses are used in achromatic telescopes?

has a higher refractive and dispersive power, the combination producing refraction without dispersion, and consequently forming an image free from the primary prismatic colors.

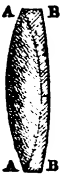
The common form of achromatic compound lens is a plano concave lens of flint glass, united with a double convex lens of crown glass. Such lenses are found in opera-glasses and spy-glasses, called achromatic, used both on land and at sea. This form of lens is also often employed in the smaller astronomical telescopes. But in such glasses a certain amount of spherical aberration remains uncorrected.

To secure perfect correction of spherical and chromatic aberration at the same time, a double concave lens of flint glass has been placed between two double convex lenses of crown glass, the curved surfaces of the several lenses being carefully estimated in view of the refractive and dispersive powers of the two kinds of glass employed.

The refractive and dispersive powers of glass are so variable, that the optician is obliged to determine them anew for every new specimen of glass, and estimate again, by the formulæ already given, the proportional curvatures of the lenses to be constructed from it.

Sir John Herschel found that an achromatic object-glass of the form shown in fig. 449, will be nearly free from spherical aberration, if the exterior surface of the crown lens is 6·72, and the exterior surface of the flint lens 14·20, the focal length of the combination being 10·00, and the interior surfaces of the two lenses being computed from these data to destroy the chromatic aberration by making the focal lengths of the two glasses in the direct ratio of their dispersive powers. The two interior surfaces that come in contact may be cemented together if the lenses are small.

449



Until quite recently, almost insuperable obstacles interfered with the manufacture of flint glass in large pieces of uniform density, free from veins and imperfections.

In 1828, an achromatic lens fourteen inches in diameter was considered a true marvel of optical art. The object glass in the great achromatic refracting telescope at Cambridge, Mass., (one of the largest in use,) is about sixteen inches in diameter, with a clear aperture of fifteen inches, and it cost, unmounted, about $15,000. M. Bontemps, a French artist, employed in the glass works of Messrs. Chance, Brothers & Co., Birmingham, Eng., has succeeded in producing a disk of

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What is the best form of achromatic lens? 814. How are equatorial mountings for telescopes constructed?

flint glass twenty-nine inches in diameter, two and a half inches thick, weighing two hundred pounds, and pronounced by the most skillful opticians very nearly faultless.

814. **Equatorial mountings for telescopes.**—With telescopes of great power, the diurnal motion of the earth causes a celestial object to pass out of the field of view too rapidly to allow of satisfactory observation. To obviate this difficulty, a system of machinery called an equatorial mounting, has been devised, to give to the telescope such a uniform motion as to keep any celestial object constantly in the field of view. An axis firmly supported is placed parallel to the axis of the earth, and is caused to revolve by clock-work with a motion exactly equal to the siderial motion of the heavens. A second axis, across which the telescope is mounted, is mounted upon the first axis, and at right angles with it. The telescope can be elevated or depressed in declination by motion of the second axis, and it can be moved in right ascension by motion on the first axis. When the telescope has been thus directed to any celestial object, it may be clamped on both axes, and the movement of the clock-work will cause it to follow the motion of the object in the heavens.

815. **The Cambridge telescope with equatorial mountings** is shown in fig. 450, copied from a figure by Prof. Loomis.

It stands on a granite pier surmounted by a single block of granite ten feet in height, to which the metallic bed-plate of the telescope is secured by bolts and screws. It is covered by a dome moving on a circular railway, which is easily rotated so as to allow the great telescope, twenty-three feet in length, to be directed to any part of the heavens. A narrow window, closed by shutters moved by chains, is opened when the telescope is in use. The hour circle attached to the equatorial axis is eighteen inches in diameter, divided on silver, and reads by two verniers to one second of time. The declination circle is twenty-six inches in diameter, divided on silver, and reads by four verniers to four seconds of arc.

The movable portion of the telescope and machinery is estimated to weigh about three tons, but it is so perfectly counterpoised and adjusted that the observer can direct the instrument to any part of the heavens by a very slight pressure of the hand upon the balance rods. This great achromatic telescope has eighteen different eye-

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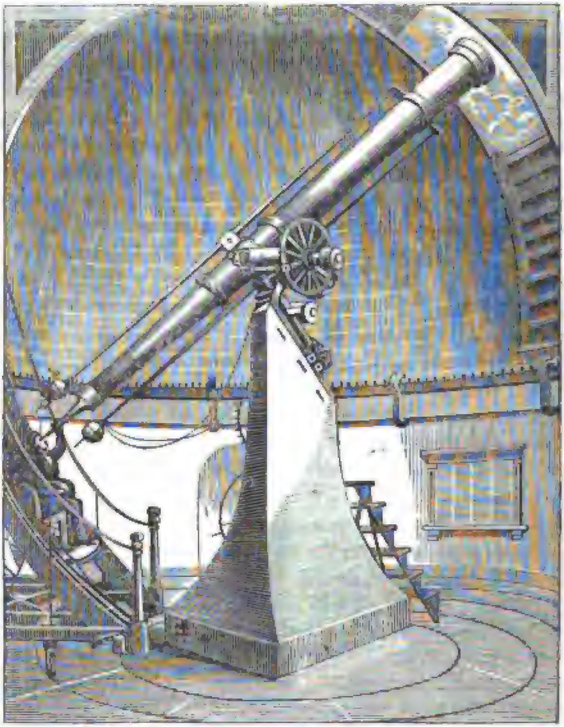
815. Describe the Cambridge telescope and its mounting. What is its range of magnifying power?

pieces, giving to the instrument magnifying powers varying from 103 to 2000 diameters.

450



816. **Achromatic object glasses for microscopes**, if constructed of the forms used in telescopes, are very unsatisfactory.. In the first place it is found exceedingly difficult to construct such lenses sufficiently small for the high magnifying powers required in the microscope. Secondly, the largest achromatic lenses for telescopes have but a small diameter in proportion to the length of their foci, and if lenses for the microscope have a diameter equally small in proportion to their foci, they admit too little light to be of much practical utility. But if their diameter is increased, the light admitted through the borders of the lenses

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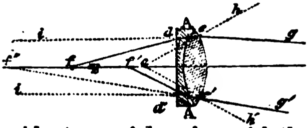
816. What difficulties are encountered in applying achromatic lenses to the microscope?

produces fringes, with colors in the inverse order of the solar spectrum, showing that while the color is perfectly corrected in the centre, the correction effected by the concave lens is too great at the margin.

817. **Lister's aplanatic foci, and compound objectives.**—The discoveries of Joseph Jackson Lister, Esq., read before the Royal Society in 1830, have proved of the utmost value in perfecting the compound achromatic microscope. His preliminary principles are 1st, that plano convex achromatic lenses, shown in fig. 437, are most easily constructed. 2d, that if the convex and concave lenses have their inner surfaces of the same curvature, and are cemented together, much less light is lost by reflection than if the lenses are not cemented. Mr. Lister discovered that every such plano convex achromatic combination as *A A*, fig. 451, has some point, as *f*, not far from its principal focus, from which radiant light falling upon the lens will be transmitted free also from spherical aberration. This point is therefore called an *aplanatic focus*. The incident ray, *f d*, makes with the perpendicular, *i d*, an angle considerably less than the emergent ray, *e g*, makes with *e h*, the perpendicular at the point of emergence. The angle of emergence is nearly three times as great as the angle of incidence, and the rays emerge from the lens nearly parallel, or converging towards a focus at a moderate distance from the lens.

451



If the radiant point is now made to approach the lens, so that the ray *f d e g* becomes more divergent from the axis, as the angles of incidence and emergence become more nearly equal to each other, the spherical aberration becomes negative or over-corrected. But if the radiant point, *f*, continues to approach the glass, the angle of incidence increases, and the angle of emergence diminishes, and becomes less than the angle of incidence, and the negative spherical aberration produced by the outer curves of the compound lens, becomes again equal to the opposing positive aberrations produced by the inner curves which are cemented together. When the radiant has reached this point, *f'*, (at which the angle of incidence does not exceed that of emergence so much as it had at first come short of it,) the rays again pass the glass, free from spherical aberration. The point *f'* is called the shorter aplanatic focus.

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817. Whose discoveries have principally conduced to obviate these difficulties? State Mr. Lister's two preliminary principles. Explain the phenomena of aplanatic foci of achromatic lenses.

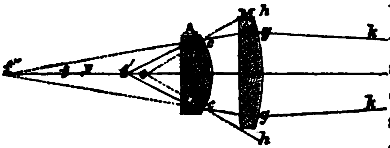
For all points between the two aplanatic foci *f* and *f'* the spherical aberration is over-corrected, or negative; and for all radiant points more distant than the longer aplanatic focus *f*, or less distant than the shorter aplanatic focus *f'*, the spherical aberration is under-corrected, or positive. These aplanatic foci have another singular property. If a radiant point in an oblique or secondary axis is situated at the distance of the longer aplanatic focus, the image situated in the corresponding conjugate focus will not be sharply defined, but will have a coma extending outwards, distorting the image. If the shorter aplanatic focus is used, the image of a point in the secondary axis will have a coma extending towards the centre of the field. These peculiarities of the coma produced by oblique pencils are found to be inseparable attendants on the two aplanatic foci.

These principles furnish the means of entirely correcting both chromatic and spherical aberration, and of destroying the coma of oblique pencils, and also of transmitting a large angular pencil of light free from every species of error.

Two plano convex achromatic lenses, *A M*, fig. 452, are so arranged that the light radiating from the shorter aplanatic focus of the anterior combination, is received by the second lens in the direction of *f'*, its longer aplanatic focus.

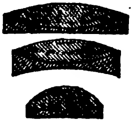
If the two compound lenses are fixed in this position, the radiant point may be moved backwards or forwards within moderate limits, and the opposite errors of the two compound lenses will balance each other.

452



Achromatic lenses of other forms have similar properties. It is found in practice that larger pencils free from errors can be transmitted by employing three compound lenses, the middle and posterior combinations being so united as to act as a single lens, together balancing the aberrations of the more powerful anterior combinations. Fig. 453 shows a common form of the triple aplanatic and achromatic objective, used for the compound microscope.

453

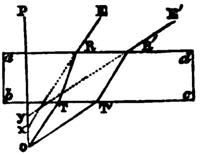


What is the character of the aberration for radiant points between the aplanatic foci? What phenomena are observed with oblique pencils? How are two achromatic lenses combined to produce the best effect? What advantage is obtained by combining three compound lenses?

818. **Aberration of glass cover corrected.**—If an object viewed with an achromatic microscope, which has all its aberrations corrected for an uncovered object, is covered with even a thin film of glass or mica, spherical aberration is again produced, thus sensibly impairing the distinctness of vision when a high power is used.

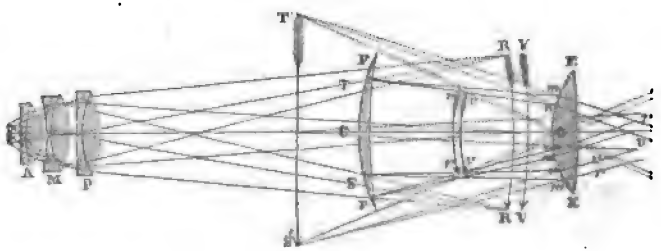
Let *a b c d*, fig. 454, be a film of glass or mica bounded by parallel surfaces. If rays of light, diverging from *O*, pass through this film, the ray, *O T′ R′ E′* will suffer greater displacement than the ray *O T R E*, which makes a smaller angle with the perpendicular *O P*. If *R E* and *R′ E′* are extended backward, they will cross the axis or perpendicular at the points *X* and *Y*. This separation of the points *X* and *Y* is exactly similar to the spherical aberration of a concave lens, and is therefore called negative spherical aberration. Chromatic aberration is also produced by the same means. The effect observed by the eye in such cases is, that lines are not so sharply defined, and the outline of an object appears bordered with broader fringes, with colors of the secondary spectrum upon the borders of the object. These errors are easily corrected by diminishing the distance between the anterior and posterior combinations of the compound objective, which is furnished with an adjusting screw for this purpose.

454



819. **The compound achromatic microscope** is composed of the triple achromatic objective, *A M P*, fig. 455, and the negative eye-piece, formed of the field lens *F F*, and the eye lens *E E*.

455.



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818. What effect is produced by covering an object with thin glass? Explain how a plate of glass produces spherical aberration of diverging rays? Why is this called negative aberration? How is this aberration corrected in the compound achromatic objective? 819. What are the essential parts of a compound achromatic microscope?

The section shown in the figure, shows how the light is acted upon in passing through the different parts of the instrument. Pencils of rays from all parts of the object *s t*, pass through the compound objective *A M P*, and tend to form a red image at *R R*, and a violet image at *V V*, the object-glass being slightly over-corrected, so as to project the violet rays as far beyond the red as may be necessary to make up for the want of absolute achromatism in the eye-piece. The converging pencils *S C T*, being intercepted by the field lens *F*, are foreshortened, and at the same time the lateral pencils are bent inward, so that the images *v v*, *r r*, are smaller, nearer together than *V V*, *R R*, and curved in an opposite direction. The reversion of the curvature of the images is produced by the form of the field lens, which meets the central pencil, *C*, much farther from the images *V V*, *R R*, than where it meets the lateral pencils *S T;* thus the focus of the central pencil is more shortened than the others. The field lens of the negative eye-piece does not reverse the curvature, in every variety of instrument, but it always changes the form of the images so as to improve the definition. The violet rays *S n*, *T n*, fall upon the eye-lens nearer its axis, than the red rays *S m*, *T m*, which are less refrangible, and hence the eye lens counteracts the divergence of the colored rays which were separated by the field lens, and causes them to pass to the eye so nearly parallel, that they appear to diverge from the same point of the virtual image *S T*, formed at the distance of distinct vision. The distance between the red and violet images *r r*, *v v*, is just equal to the difference between the red and violet foci of the lens, and these images being curved just enough to bring every part into exact focus for the eye lens, the eye sees the image at *S' T'*, spread out in its true form on a flat field.

By means of this beautiful system of compensations, for the various errors of chromatic and spherical aberration and curvature of the image, which interfere with the performance of a single lens, the compound achromatic microscope has been brought to a degree of perfection unsurpassed by any instrument employed in practical physics.

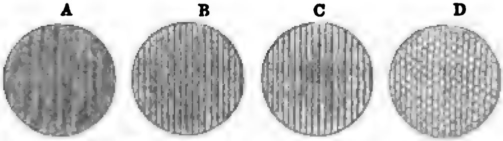
820. **Angular aperture.**—The amount of light by which any point of an object appears illuminated, depends on the angular breadth of the pencil of light by which it is viewed. The angular breadth of the pencil of light which a lens transmits, is called its angular aperture.

The minute details of an object viewed by a microscope, are seen with greater distinctness, in proportion to the angular aperture of the object glass employed.

For what purpose is the object glass over-corrected? Explain the action of the negative eye-piece in connection with the achromatic objective. 820. What is meant by angular aperture?

In fig. 456, *A, B, C, D,* show the successive appearances of a transverse section of wood, by regular enlargements of the angular aperture

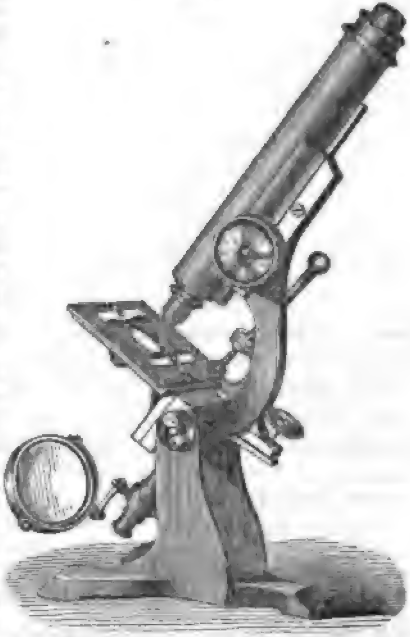
456



of the microscope with which it was viewed. The available angular aperture of a single lens seldom exceeds fifteen or twenty degrees. In the triple achromatic objective, the aperture for ordinary observations has been extended to 100°. With the highest powers used for viewing infusoria, both English and American opticians have advanced the angular aperture to 150°, and in some glasses to 175°.

821. **The mechanical arrangement of the microscope is well** exhibited in fig. 457, which has been engraved from a very excellent instrument, manufactured by J. & W. Grunow, New Haven, Conn.

457



The instrument is mounted on trunnions, which allow it to be inclined at any angle. The body of the microscope is moved in a grooved support, by a rack and pinion motion for adjusting the focus. The stage has a fine, delicate movement, by a screw and milled head, acting upon a lever at the back of the instrument, by which movement the focus can be adjusted with the utmost delicacy.

The stage itself can be moved freely in any di-

How is the definition of an object affected by the angular aperture of an object glass? How large angular aperture has been obtained in the best microscopes? 821. Describe the mechanical structure of the compound microscope.

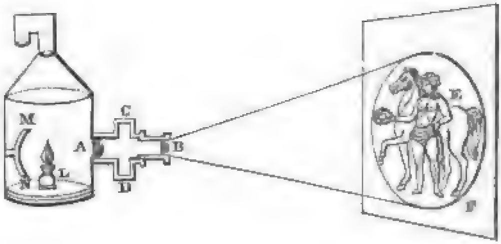
rection by a lever at the right. A mirror, concave on one side and plane on the other, is so mounted below the stage as to give a condensed pencil of light for illuminating the object.

Polarizing apparatus, and other accessories, are fitted to the stage, and to the body of the microscope.

822. **The magic lantern** is an instrument for projecting upon a screen, images of transparent pictures painted on glass.

A lamp is placed in a dark box, before a parabolic reflector, *M N*, fig. 458, which throws the light upon a convex lens, *A*, by which it is strongly condensed upon the object painted on the glass slide, inserted at *C D*. The magnifying lens, *B*, forms an image of the illuminated picture upon a screen, placed at its conjugate focus. The picture is placed in an inverted position, to produce an erect image upon the screen.

458



A great variety of objects painted on glass can thus be exhibited either for amusement or instruction. The magnifying power of the magic lantern is equal to the distance of the screen from the lens, *B*, divided by the distance of the lens from the object.

823. **The solar microscope** is a species of magic lantern illuminated by the sun. It is however much more perfect in its structure, and it is commonly employed for viewing on a screen images of natural objects, very highly magnified.

The structure and arrangement of the solar microscope are shown in fig. 459. It is mounted over an opening in the shutter of a dark room, on the side towards the sun. A plane mirror, M, is so arranged outside the shutter as to reflect the rays of sunlight, *S*, through the condensing lens, *A*, into the microscope. By turning the screw, *B*, the mirror may be elevated or depressed, and by means of another

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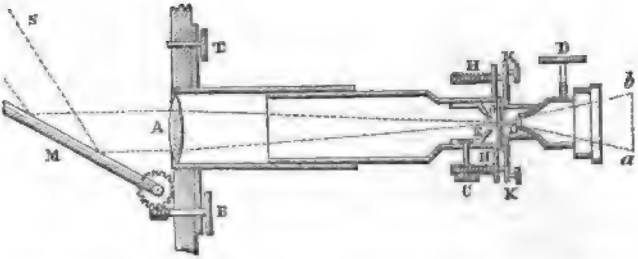
822. What is the magic lantern? Describe its construction and the method of using it. How is the magnifying power of the magic lantern determined? 823. What is the solar microscope?

screw, *T*, it can be rotated on the axis of the microscope, so as to follow the motions of the sun. A small lens, *E*, moved by the rack

459



and pinion with the milled head *C*, serves to condense the light upon the object slide, *O*. The slide *O*, which carries the object, is secured between the brass plates *K K*, by the screws *H H*.

The object, strongly illuminated, is adjusted to the focus of the small lens, *L*, (which may be either a small globule of glass, or a compound achromatic objective, of short focus,) and an image, *a b*, greatly enlarged, formed in the conjugate focus of the lens, is received upon a white screen placed in a convenient position. By diminishing the distance between the object and the lens, *L*, the conjugate focus will be increased, the screen may be placed at a greater distance from the lens, and the magnifying power will be proportionally increased.

Instead of employing the light of the sun, the solar microscope may be illuminated by the electric, or by the oxhydrogen light.

824. **The camera obscura** consists of a dark chamber in which external objects are formed by the aid of a mirror, and a concave lens. This instrument affords a convenient method of sketching natural scenery.

A plane mirror, *m*, fig. 460, placed at an angle of 45° with the horizon, reflects the light downward, through a converging lens, placed in the top of the dark chamber. A sheet of paper placed on the table in the focus of the lens, receives the image of a landscape or other object, which can be traced with a pencil by the artist, sitting, as shown in the figure, with his head and shoulders protected from extraneous light by a dark curtain.

The student can easily prepare an instrument of this kind, by inserting a spectacle glass in an orifice in the top of a box about two

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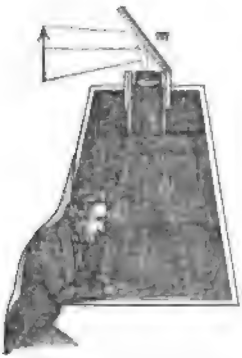
Describe its construction and the method of using it. 824. Describe the camera obscura.

feet high, and placing a common mirror at the required angle above it. The paper on the table can be placed on a drawing board, and fixed at such a distance from the lens as gives the most distinct image. A cloak thrown over the side of the box where the observer sits, will darken the chamber so as to permit sketches to be made with great facility.

460

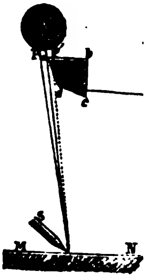


Instead of the mirror and lens shown in fig. 460, a rectangular prism is often used as a reflector, and if one side of the prism is ground in the form of a lens, the two parts of the instrument are combined in one.

825. **Wollaston's camera lucida** is another instrument used for sketching from nature. It consists of a prism, *a b c d*, fig. 461, of which the angle, *b*, is a right angle, the angle, *d*, is 135°, and the angles at *a* and *c* are each 67½°.

It is mounted on a suitable stand, and the eye, *P P′*, placed as shown in the figure, sees the image of a distant object as though projected upon the paper *M N*, where the outline may be traced by the pencil *S*, the eye seeing the image and the pencil at the same time. The light from a distant object entering the prism nearly at right angles with the face, *b c*, twice suffers total reflection, and emerges perpendicular to the face *a b*, when it enters the eye, and appears as if coming from the paper, *M N*. The image projected upon the paper is as much smaller than the object as its distance from the prism is less than the distance of the object. The image can be made to assume any required dimensions by varying the relative distances of the paper and the object. This instrument is principally employed by artists for sketching landscapes.

461



A number of other forms of camera lucida are employed to suit different purposes, but in all of them, either the object, or the pencil and paper, are viewed by reflected light, made to coincide in direction with the direct light.

826. **Photography** is the art of producing pictures by the chemical action of light. The daguerreotype, ambrotype, crystalotype, and photo-lithograph, are all produced by modified ap-

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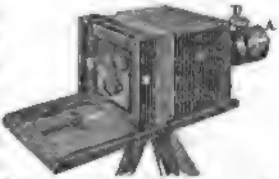
For what purpose is it used? 825. Describe Wollaston's camera lucida. How is this instrument used?

plications of the camera obscura. Instead of the plain paper and pencil used by the artist for sketching with the camera, a surface of silver or collodion, made sensitive by iodine, bromine, or some other chemical preparation, is placed in the camera and subjected to the action of the light of the image projected there by the lens.

A camera employed for photography in any of its forms, requires to be achromatic, and also that the chemical rays shall be brought to a focus at the same point as the visual rays, or at a well defined distance from them. As objects copied by photography are seldom flat, the objective of the camera requires to be so constructed as not only to give perfect definition of all objects situated in the focal plane, but also it should be adapted to give tolerably good definition of parts of an object that are situated a little anterior or posterior to the focal plane.

462



The usual form of the camera employed in photography, is shown in fig. 462. The achromatic compound lens, *A*, is attached to the box *C*, and can be moved backwards or forwards by turning the milled head, *D*. The second box, *B*, slides within the first. A plate of ground glass set in the frame *E*, is inserted in *B*, and when the focus is so adjusted as to give a perfect image on the ground glass, this is removed, and the sensitive plate covered by a dark screen is inserted in its place. The dark screen is then removed, and the light produces a chemical change where the image is projected. This image is then made permanent by vapor of mercury or other chemical applications.

827. **Railway illumination.**—For illuminating railroads, it is important to throw upon the track a powerful beam of light, consisting of rays nearly parallel. When the track is thus illuminated, objects upon it are more readily distinguished by contrast with surrounding darkness; it is therefore desirable to limit the light to the immediate vicinity of the track.

The common method of effecting this object is to place an Argand lamp in the focus of a large parabolic reflector, (406,) situated in front of the locomotive. The light is thus thrown forward in parallel

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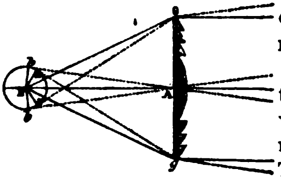
826. What is photography? By what instrument are the various kinds of photographic pictures obtained? Describe the camera employed in photography. 827. What kind of illumination is required upon railways? What instrument is employed for this purpose?

lines, and the lateral illumination produced by light radiated directly from the lamp is comparatively small.

828. **The Fresnel lens**, a section of which is shown at *o A g*, fig. 463, is also employed for projecting a powerful beam of parallel light upon objects to be illuminated at a distance. This form of lens, invented and first applied to practical purposes by Fresnel, consists of a central plano convex lens, surrounded by segmentary rings, with curvatures successively diminishing as much as is necessary to avoid the spherical aberration of a single lens, the central lens, and all the angular segments having their curves so adjusted as to have a common focus.

463



The segmentary rings are sometimes made entire, but generally, when the size is considerable, each ring is composed of several parts. The central lens and lateral segments are all cemented to a plate of glass, as shown in the figure.

For most purposes, where the Fresnel lens is employed, it is necessary to give the illuminating beam of light a slight degree of divergence. It will be easily seen from the figure, that if the center of the lamp is placed at *F*, the principal focus of the lens, the divergence of the beam, after passing the lens, will be equal to the angle *b A b*, which the flame of the lamp subtends at the surface of the lens. A concave mirror is also placed behind the lamp, to throw forward the light in a condition to be refracted nearly parallel by the lens in front of the lamp. A much more brilliant beam of light is obtained in this manner than by the parabolic reflectors alone. This lens is also used in France for railway illumination.

829. **Sea-lights**, designed as beacons to the mariner upon dangerous coasts, or for lighting harbors, are usually placed in towers, called *light houses*. . The great elevation of the light, permits it to be seen far out at sea. It is evident that all light thrown out above or below the plane of the horizon, is of no avail to the mariner.

By an ingenious application of the principles of the Fresnel lens, a sheet of light is thrown out in every direction in the plane of the horizon. If fig. 464 is revolved about the central perpendicular line, as an axis, it will generate the apparatus known as the *Fresnel*

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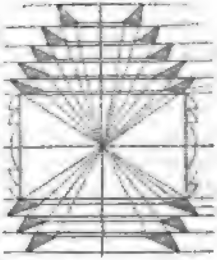
828. What is the pecular construction of the Fresnel lens? 829. Where are sea-lights usually placed?

fixed light. The central zone will consist of a series of hoops whose perpendicular section is everywhere the same as a section of the Fresnel lens. This zone will therefore so act upon the light of a lamp placed at the centre, as to project a sheet of light in every direction in the plane of the horizon. Above and below the central zone, are series of triangular hoops. A section of one of these hoops, and its action upon light radiating from the central lamp, is shown in fig. 465; *A C* and *B C* are plane faces, while *A B* is a convex surface. Light from the focus, *F*, is refracted on entering the face *B C*, it undergoes total reflection at the surface *A B*, and a second refraction at *A C*, from which it emerges in lines parallel to the horizon.

464



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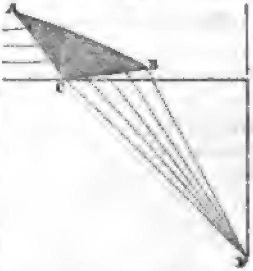
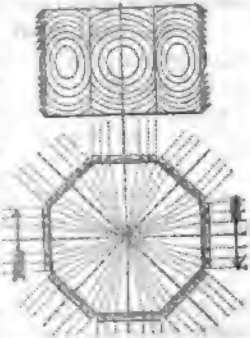


The focus of each prismatic hoop is carefully calculated for the place it is to occupy, so that every part of the apparatus throws out the light that falls upon it in a horizontal direction.

830. **Revolving lights.**—To distinguish one light-house on the coast from another, the Fresnel light is so modified as to give a steady light, and also revolving flashes of light of very great intensity.

In the *revolving Fresnel light*, the triangular prismatic hoops above and below the central zone are the same as for the fixed light, but the central zone is made of eight Fresnel lenses, fig. 466, set as shown in the lower part of figure. The upper part of the same figure shows a front view of the central zone. While the entire apparatus revolves as shown by the direction of the arrows, each of the eight lenses gives a very intense light in certain directions, and between any two there is no light from the central zone of lenses. The light seen from any position appears gradually to increase to very great brilliancy, and then to fade away to much less than half its maximum intensity,

466



Describe the Fresnel fixed light used in light-houses. Describe fig. 465. 830. Describe the Fresnel apparatus for a revolving light.

after which it again increases to its former brilliancy. These changes are repeated at regular intervals.

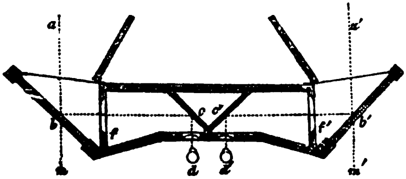
The lamp used for the Fresnel light is an Argand burner, with four concentric wicks, with currents of air passing up between them.

The wicks are defended from the excessive heat of their united flames by a superabundant supply of oil, which is thrown up from below by a clock-work movement, and constantly overflows the wicks. A very tall chimney is required to supply a sufficiently strong current of air to support the combustion. The dimensions of the Fresnel light, and the number of lenses and hoops of which it consists, are varied to suit the purposes for which it is used; the light produced varying in intensity from twenty-five to three thousand Argand lamps of common size.

831. **The telestereoscope** is an instrument which causes distant objects to appear in relief. The image upon the retina of every human eye represents a perspective projection of the objects situated in the field of view. As the positions from which these projections are taken are somewhat different for the two eyes of the same individual, the perspective images themselves are not identical, and we make use of their difference to obtain an idea of the distances from the eye of the different objects in the field of view. The images of the same object on the two retinæ are more different from each other as the object is brought nearer to the eyes. In the case of very distant objects, the difference between the pictures on the retinæ of the two eyes becomes imperceptible, and we lose the aid just spoken of in estimating their distance and bodily figure.

The telestereoscope increases the binocular parallax of distant objects, and by presenting to each eye such a view as would be obtained if the distance between the two eyes were greatly increased, it gives the same appearance of relief, as if the objects were brought near to the observer.

467



What kind of a lamp is used for the Fresnel light? 831. Why are the pictures formed on the retinæ of the two eyes different? How does this difference vary in different positions?

Let *b* and *b'*, fig. 467, be two plane mirrors placed at angles of 45° with the line of vision; let *c* and *c'* be two smaller mirrors placed parallel to *b* and *b'*, and let *d* and *d'* represent the position of the two eyes of the observer. It is evident that the light from distant objects falling upon the mirrors in the direction *a b* and *a' b'*, will be reflected to the small mirrors *c* and *c'*, where it will be again reflected to the eyes at *d* and *d'*. The two views seen by the eyes will evidently be the same as if the eyes were separated to the positions *m* and *m'*. The relief with which objects will be seen by this instrument, will obviously be increased as much as the distance *b b'*, exceeds the distance between the eyes *d* and *d'*.

But while the perspective difference of the images seen by the two eyes has been increased, the visual angle under which each object is seen remains unchanged, and hence, as the apparent distance of the objects is diminished, their dimensions appear diminished in the same proportion. If the small mirrors are made to rotate on perpendicular axes, while the large mirrors are fixed, the distortion of figure may be easily corrected by turning the small mirrors until objects appear in their true proportions. If the lenses of an opera glass are inserted in the instrument, the convex field glasses being inserted at *f* and *f'*, between the large and small mirrors, and the concave eye glasses between the eyes and small mirrors, the effect will be to increase the visual angle of every object in the field of view. If the glasses magnify as many diameters as the distance between the large mirrors exceeds the distance between the eyes, every object will appear in its due proportions, and the effect will be surprising. The appearance will be as though the observer had been actually transported to the immediate vicinity of the objects themselves. The distance between the large mirrors of the telestereoscope should not exceed the breadth of an ordinary window, unless it is to be used in the open air, when it may be made of any dimensions that are desired, and the effect produced will be in proportion to its magnitude.

832. **The stereoscope** is an instrument by which two pictures of an object give the appearance of a solid structure. If two photographs of distant objects are taken from positions at such a distance as to give an appropriate difference of perspective, they may be viewed in an instrument called a stereoscope, which will give them all the relief and solid appearance of real objects.

If two pictures of an octahedron, as *A* and *B*, fig. 468, such as

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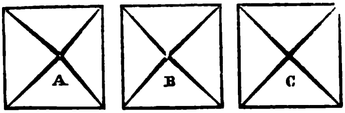
What is the design of the telestereoscope? Explain its construction. What effect is produced by inserting the lenses of an opera-glass in the telestereoscope? 832. How may pictures be made to show the objects in relief?

would be formed on the retinæ of two eyes, are placed in the stereoscope, fig. 469, they give to the observer the idea of real solid octahedron, instead of the ordinary picture, *C.* Photographs of natural scenery, taken from two positions, when viewed in this instrument, appear in relief like real objects.

468



The construction and action of the stereoscope will be readily understood by reference to figs. 470, and 471. From a double concave lens, *A B A′ D*, two eccentric lenses, represented by the smaller circles, are formed. *E A e*, in the lower part of the figure, represents a transverse section of one of these eccentric lenses, and *E A′ e* the other. Each lens is equivalent to a triangular prism *E A e*, with a plano convex lens cemented to each refracting face of the prism. Fig. 471 shows a section of the stereoscope, the eccentric eye-lenses *A E*, *A′ E′*, being placed at the ordinary distance of the eyes, with their thin edges towards each other. Let *P* and *P′* represent two corresponding points in the stereoscopic photographs which are to be examined. The rays of light, diverging from the point *P*, falling upon the eye-lens, are refracted nearly parallel, and by the prismatic form of the lens are deflected from their course, and emerge from the lens in the same direction as if emanating from the point *O*. In the same manner the rays from the point, *P*, also appear to diverge from the point *O*. The same is true of all similar parts of the two pictures; thus the pictures appear

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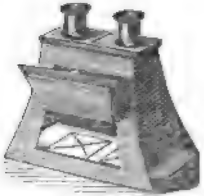

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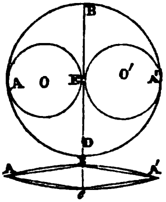

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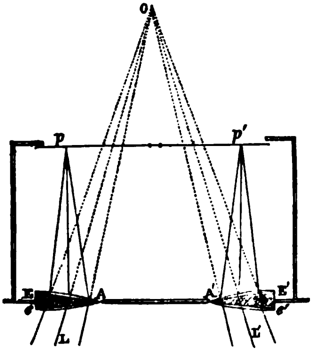

Describe the lenses used in the stereoscope? How do these lenses act in the stereoscope to cause two pictures to appear as one? Why does the stereoscope give the appearance of relief?

superimposed upon each other, and together produce the appearance of relief, for which the stereoscope is so much admired.

The eccentric lenses of the stereoscope are sometimes fixed in position, but they are often inserted in tubes, as in fig. 469, which can be extended to adapt the focus to different eyes, or separated to a greater or less distance, to suit the distance between the eyes of different persons.

If stereoscopic photographs are taken from positions too widely separated from each other, objects stand out with a boldness of relief that is quite unnatural, and the objects appear like very reduced models. In taking stereoscopic miniatures especially, great care is required to preserve a natural appearance. In general, a difference of a few inches in the two positions of the cameras, gives sufficient relief to the pictures when seen in the stereoscope.

For public buildings and landscapes, two cameras are usually employed, placed on a stand three or four feet from each other. If it is desired to show a great extent of a distant landscape, or to exhibit in miniature the grouping and form of distant mountains, two stations should be selected that are widely separated; but in such cases, care should be taken that no near objects are admitted into the picture.

833. **The stereomonoscope**, (lately described by Mr. Claudet, of London,) is an instrument by which a single picture is made to present the appearance of relief commonly seen in the stereoscope, and by means of which several individuals can observe these effects at the same time.

Let *A*, fig. 472, be an object placed before a large convex lens, *L*, an image of the object will be formed at *a*, in the conjugate focus of the lens, and from the image *a*, the rays of light will diverge as from a real object, which will be seen by the eyes placed at *e e*, *e′ e′*, or any other position, in the cone of rays *b a c*. Thus several persons may at the same time see the image suspended in the air. If a screen

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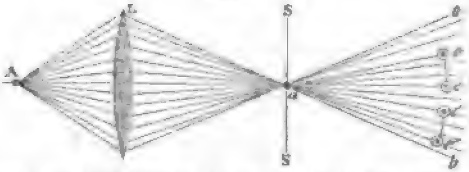

What precautions are necessary in taking stereoscopic photographs? 833. What is the stereomonoscope? Explain its structure and use. How does this instrument enable several persons to see the same object simultaneously?

of ground glass is placed at *S S*, the image will appear spread out upon the glass, but it will appear with all the perspective relief of a real object. An image thus formed on ground glass can be seen only in the direction of the incident rays. This is not the case with an image formed on paper, which radiates the light in all directions, and is hence incapable of giving a stereoscopic effect in such circumstances.

The stereomoscope consists of a screen of ground glass, *S S*, fig. 478, and two convex lenses, *A L*, *B L*, so placed as to form images of two stereoscopic pictures, *M* and *N*, at the same point on the screen *S S*. Though the two pictures have their images superimposed on the screen *S S*, each picture can be seen only by the rays proceeding from the photograph by which it was formed. If the eyes are so placed that the right eye is in the direction of the rays coming from one lens, and the left eye in the direction of rays coming from the other lens, the object will appear in relief as in the stereoscope, and several persons can witness the effect at the same time.

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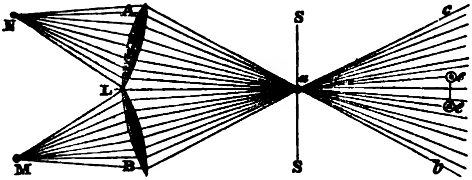

PHYSICAL OPTICS.

834. **Interference of light.**—The interference of vibrations and waves, has been already alluded to in the *theory of undulations*, (408, 414,) but the phenomena of luminous interference require some further special consideration.

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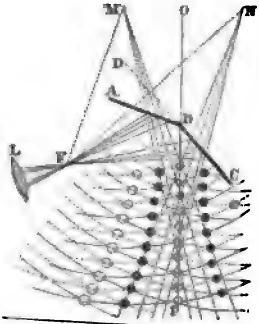

Let *A B*, *B C*, fig. 474, be two plane mirrors, making with each other a very obtuse angle; (very near 180°;) let a beam of sunlight, entering a dark room by a small opening, be brought to a focus by a lens, *L*; if this light, diverging from a focus, is allowed to fall very obliquely upon the two mirrors, as shown in the figure, it will be reflected as if diverging from two luminous points, *M* and *N*, and the light thus reflected will be in a condition to interfere. Draw *O P* perpendicular to *M N*, from a point *O*, midway between them. It is evident that every point in the line *B P*, will be equally distant from the lu-

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834. How can the phenomena of interference of light be exhibited?

minous points *M* and *N;* the waves of light which cross each other in the line *B P*, will therefore be in the same phase of vibration, and consequently produce a line of light of double intensity. Let the smooth circular arcs represent the phases of elevation, and the dotted arcs phases of depression, then where a dotted arc crosses a smooth arc, the two waves should counteract each other and produce darkness. The open dots represent vibrations meeting in the same phase, and the black dots represent vibrations meeting in opposite phases, which produce darkness. The symmetrical curves formed by the intersection of light from the two points *M* and *N*, on both sides of the central line, are of the form known in geometry as hyperbolas.

The distance on each side of the line *B P*, where the luminous waves will be again in a like state of accordance represented by the crossing of the smooth arcs in the figure, will depend on the interval between them, which is different for different colors; for red, it is half as much again as for violet light; hence the distance between the curves of double intensity will be least for violet light, greatest for red, and intermediate for the other colors of the spectrum, so that while all the colors are united in the central line *B P*, they will be separated in the other bars, and form a series of colored fringes. In experiments, this serves to distinguish the central bar, namely, that the other bars are colored symmetrically on each side of it.

Now half way between two places of complete accordance there must occur a place of complete discordance, where the difference of distances from *M* and *N* is $\frac{1}{2}$ an interval, or $\frac{3}{2}$, $\frac{5}{2}$ or $\frac{7}{2}$, &c.; and according to the undulatory theory, there would be complete darkness. Between these and the places of complete accordance, there would be intermediate stages of accordance and discordance; hence there would be bright bars shading into dark ones, all more or less colored except the central bars, where all the colors are in a state of complete accordance.

By careful measurement of distances between the luminous and dark bars, the lengths of luminous waves of different colors have been very accurately ascertained.

835. **Facts at variance with theory.**—When the atmosphere is free from clouds, and the sunlight is brightest, the *central* bar, (which, according to theory, should be *bright*,) is found to be a *black one*, whatever be the material of which the mirrors are composed. But when the sun is near setting, the central bar has been seen undoubtedly a *bright* one. It has also been seen

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What is the form of the bright and dark bands produced by interference? Why are these bands bordered with colored fringes? 835. What is the appearance of the central band when ordinary sunlight is used?

as a bright bar when the luminous point was formed at a hole in a thin plate of metal, and the light which had grazed the edge of the hole was used.

The existence of a *central black bar*, in normal circumstances, where the vibrations must meet in the same phase, is inconsistent with the undulatory theory of light.

It appears that light is so modified in passing through haze, or at an opaque edge of a small hole, as to acquire an *anatropy* or inversion of properties.*

836. **Interference colors of thin plates** are seen in thin films of varnish, cracks in glass, films of mica, various crystals, and in other transparent substances, as in soap bubbles. The colors of such thin films are due to the interference of light twice reflected by the surfaces of the film.

Two surfaces of glass, pressed together, furnish a thin plate of air between two reflecting surfaces. Let *C A D B*, fig. 475, be a transparent film, such as a thin blown bulb of glass, or a soap bubble; let *S A B T* be the transmitted ray, *S A R* the ray reflected at the first surface, *S A B A′ R′* the portion reflected from the second surface, and emergent at the first surface, *S A B A′ B′ T′* the portion emerging from the second surface, after the two internal reflections, then the ray *A′ R′* will be retarded behind the ray *A R*, by the interval *n m*, owing to the increased length of path it has to travel in twice traversing the film, and *B′ T′* will, in a similar manner, fall behind the ray *B T*, by the interval *p q*. If these retardations equal the interval of an odd number of half vibrations, they will interfere, as they originated from a common wave, in the ray *S A*. The reflected rays do not differ greatly in intensity, which is for each about one-thirtieth that of the incident light for glass, and therefore their interference produces blackness where they destroy each other. The transmitted light has the principal beam of little less intensity than the incident beam, having lost only about one-thirtieth part by reflection at each of the points *A* and *B*; but the intensity of the twice reflected beam which interferes with it is about one-thirtieth of one-thirtieth, or one nine-hundredth of that of the incident beam; hence the difference of the intensities of the bright

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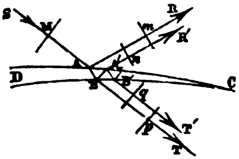

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* Potter's Physical Optics.

How does the central band vary with different kinds of light? 836. Explain the production of colors by thin plates.

and dark bands formed by transmitted light is never as great as in the reflected beams. But the difference between the bright and dark bands is different for different colors of the spectrum, being least for violet light, and greatest for red. This fact is thought to be contrary to what should have been expected, according to the undulatory theory.

837. **Newton's rings.**—If a plane plate of polished glass is pressed against a plano concave lens whose radius of curvature is known, the interference bands become colored rings, and the exact thickness of the film of air by which each color is produced is easily estimated.

The form of this apparatus is shown in fig. 476. The letters and explanation of the figure are similar to the preceding. When the two glasses are pressed sufficiently near together, the centres appear black by reflected light, and bright by transmitted light. The thickness of the film of air where the first color appears, is equal to one-half the retardation producing that color, hence the length of the wave, or vibration, for any color, is estimated as equal to twice the thickness of the film of air where the color appears. The colors succeed each other in the order of the length of the vibrations required to produce them. A second, third, and fourth series of colored rings will be found, where the thickness of the film is an exact multiple of the thickness required to produce the first series of colors. The distance between the first and second series depends on the rapidity with which the thickness of the film increases. In the case of a lens pressed against a plate of glass, the distance between the glasses, or the thickness of the film, increases as the square of the distance from the centre. The diameters of the bright rings will therefore be as the square roots of the numbers 1, 2, 3, &c., and the diameters of the dark rings will be as the square roots of the numbers 1½, 2½, 3½, &c. The distance between successive rings of violet will be much less than the distance between successive rings of red; one series of colors will therefore sometimes overlap some of the colors in the succeeding series of colored images, and by their admixture produce colors which are designated as Newton's first, second, third, &c., orders of colors.

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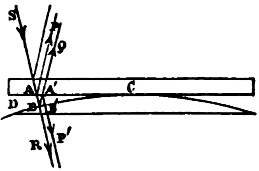

838. **Length of luminous waves or vibrations.**—By such means as we have described, the length of the vibrations required to produce different colors have been estimated.

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837. Explain the phenomena of Newton's colored rings. What is meant by the first, second, and third orders of colors?

The velocity of light determined by the eclipses of Jupiter's satellites, by the method explained in section 723, is about 192,000 miles per second.

The following table exhibits the numerical results which have been deduced for the length and velocity of luminous vibrations of different colors.

Colors.	Length undulation in parts of an inch.	Number of undulations in an inch	Number of undulations per second.
Extreme red,	0·0000266	37640	458,000000,000000
Red, . . .	0·0000256	39180	477,000000,000000
Orange, . .	0·0000240	41610	506.000000,000000
Yellow, . .	0·0000227	44000	535,000000,000000
Green, . .	0·0000211	47460	577,000000,000000
Blue, . . .	0·0000196	51110	622,000000,000000
Indigo, . .	0·0000185	54070	658,000000,000000
Violet, . .	0·0000174	57490	699,000000,000000
Extr'me viol't,	0·0000167	59750	727,000000,000000

According to Eisenlohr, (American Journal of Science, vol. 22,) the length of the vibrations in the extreme red ray is just double the length of the vibrations of the invisible rays beyond the violet, which, by concentration, produce the lavender light of Herschel. The entire range of visible rays differ in the length of their vibrations only the amount of one octave in music.

When we consider the almost inconceivable velocity with which these wonderfully minute vibrations are propagated, it is evident that absolute demonstration of the real nature of light must be among the profoundest researches of physical science.

839. **Diffraction.**—If a razor is held with its flat surface towards the rays of the sun, the rays that pass in close proximity, both to the edge and to the back, will be deflected as shown in fig. 477. A portion of the rays are deflected outwards, appearing to suffer reflection; the back of the razor deflecting the rays outward, more than the sharp edge; but the edge of the razor deflects more light into the place of the geometrical shadow, than is deflected inwards by the back of the instrument. These differences are represented by the closeness of the lines drawn to represent the rays where the greatest amount of light is deflected. If the body interposed is narrow, like a fine needle or a hair,

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838. What is the actual velocity of light as determined by observations on Jupiter's satellites? How many undulations take place in an inch for the different colors? How do the longest and shortest visible undulations compare with each other? 839. What is meant by diffraction? Explain the method of observing these phenomena.

the rays deflected inwards cross each other, and produce the phenomena of interference in *accordance* with the undulatory theory, and the rays deflected outward produce interference with the rays not deflected, but bright lines appear where the undulatory theory would give dark lines. All the bright and dark lines are bordered with colored fringes, as in ordinary cases of interference. These phenomena are best seen in a dark room by looking through an eye lens at a hair or needle, at a considerable distance from a lamp, or by looking at a beam of sunlight admitted to a dark room between two sharp parallel edges. The rays that have been diffracted or bent into the geometrical shadow, are not as readily deflected again in the same direction, but are more easily deflected in the opposite direction than rays which have undergone no such previous change.

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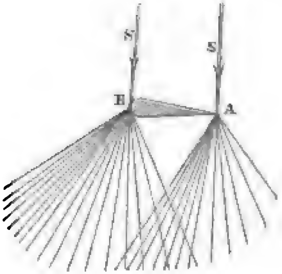
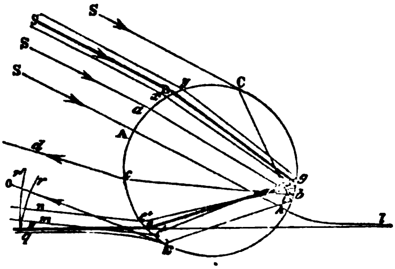


840. **The rainbow** is a phenomenon in which reflection, refraction, dispersion and interference of light, are all combined to produce one of the most wonderful and beautiful phenomena in nature. It is seen in that part of the heavens opposite to the sun, when the sun is less than forty-two degreess above the horizon. The shadow of the eye of the observer will always point to the centre of the circle of which the rainbow forms a part; hence, as the sun descends near the horizon, the rainbow rises higher, and as the sun ascends the morning sky, the heighth of the rainbow diminishes.

478



To understand the formation of the rainbow, we must first examine the action of a single drop of water upon parallel rays of light. Let the circle, fig. 478, represent a drop of water, and *S A*, *S B*, &c., parallel rays of light falling upon it. The ray *S A*,

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840. What principles are involved in the phenomena of the rainbow? In what part of the heavens is the rainbow seen?

which falls perpendicularly upon the drop, will suffer no deviation in its direction, but will be partially reflected backward in the line of incidence, though it will principally pass through the drop. The ray *S a*, will be refracted to *b*, where it will be reflected to *c*, and will emerge in the direction *c d*, making a certain angle with the direction of the original ray *S a*. As the distance of the incident ray from *A* increases, the emergent ray will make a greater angle with the incident ray, till we arrive at *B*, where two successive rays will emerge parallel, as shown by the heavy line, *S B g e p*, which deviates more from the direction *A S*, than any ray incident at a greater or less distance from *A*. As we proceed from *A*, towards *C*, the deviation of the emergent ray will diminish, and every ray between *B* and *C* will emerge parallel to some other ray, which entered the drop between *A* and *B*; *s n* will emerge in *e′ m*, parallel to *e″ n*, which entered the drop at the ray *S g*. The ray *S C*, which is tangent to the drop, will be refracted to *i*, and emerge in the direction *k o*, making an angle of about twenty-five degrees with *e p*, the line of greatest deviation.

The light which enters the drop in parallel rays will therefore emerge, spread over the entire space between *e p* and *c d*; but having its greatest intensity near the direction *e p*, and rapidly diminishing towards *c d*.

If *A Y*, fig. 479, represent the position of the line *e p* of fig. 478, the dotted curve, by its heighth above *A X*, will show how rapidly the intensity of the light fades away, as the distance from *e p* increases toward *e d*, where the intensity is zero

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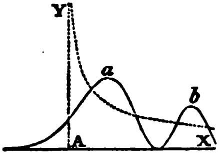

Since we have at every angle between *e p* and *c d*, parallel rays which have traversed different paths through the drop, we shall have all the phenomena of bright and dark bands, produced by interference.

The intersection of the emergent rays will form a caustic curve *k q*, tangent to the circle at *k*, and approaching constantly to parallelism with the asymptote *e p*, which it will never meet. If the emergent rays between *c* and *e* were extended backwards, they would form another caustic *h l*, having *e p* produced backward for its symptote. The caustic curve *h l*, commences in a direction perpendicular to the surface of the drop, and approaches the asymptote without ever

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Explain the action of a drop of water upon a beam of parallel light. Why is interference produced among the emergent rays? How are the caustic curves formed, and how are they situated? How many bright and dark bands may be seen in light of a single color reflected from a drop of water? How does the breadth of the interference bands vary for different colors?

touching it. The curves *q r*, formed by unwrapping a thread from the caustic *k q*, and *q r'*, formed by a thread from the caustic *l h*, show, by their gradual separation, the amount of retardation of the wave surface of the two sets of parallel rays which interfere between *e p* and *c d*.

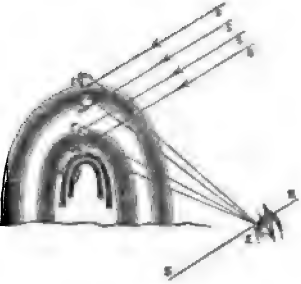
According to the undulatory theory, we shall have bright bands where the rays have traversed equal distances, or distances differing by any number of entire vibrations, and dark bands where the rays differ by an odd number of half vibrations.

These bright and dark bands are readily seen, with proper precautions, with light reflected from a drop of water suspended at the point of a fine glass tube. When mono-chromatic light is used, thirty or forty of these bright and dark bands may be counted.

The breadth of the bright and dark bands varies with the size of the drop from which the light is reflected. The interference bands vary also for the different colors, being nearly twice as broad for red as for violet light. When white light is employed, the first red band only is pure, the other bands being more or less confused by the unequal super-position of different colors.

If we consider only the first two bright bands of each color, we can easily explain the common phenomena of the rainbow. A little within the caustic curve, *k q*, fig. 478, on its convex side, we shall have a bright light, represented in intensity by the curve *a*, fig. 479, and a second band of the same color at *b*, of feebler intensity. As the refractive index for red rays is less than for the other colors, the red will diverge more from the incident ray, after refraction, than the violet, and other colors will appear intermediate.

480



Suppose now that in a shower of rain a ray of light from the sun falls upon a drop of water at *r*, fig. 480, and is reflected from its posterior surface, so as to give to the eye the red ray of maximum intensity, *r E*, a drop below it will give a violet ray of maximum intensity, *v E*, and intermediate colors will be formed in the same manner by intermediate drops. Let the planes of

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Explain the formation of the rainbow? Why is the rainbow curved? What effect is produced when the rain-drops vary greatly in size? How is the secondary rainbow formed?

incidence and reflection revolve about a line $S\,E\,S$, drawn from the sun through the eye of the observer, and the position of the drop, from which light can reach the eye, will describe the arch of the rainbow.

The purity of the several colors in the rainbow is the result of interference, which produces dark bands for each particular color, giving a clear space for the delineation of each color of the rainbow before the first color is repeated. When the rain-drops differ greatly in size, as is often the case, the different colors of the first and second interference bands overlap and mingle together, and the bow is but imperfectly developed.

A *secondary rainbow*, with violet above and red below, is formed by light which has been twice reflected within the drops, as shown in fig. 480, the rays entering the lower border of the drop, and emerging near the upper border. The same principles of interference determine the purity of colors, and angle of maximum intensity, as in the primary bow. The loss of light occasioned by two reflections accounts for the feebler intensity of the secondary rainbow. In the secondary rainbow, the order of colors is the reverse of the primary, violet being outermost.

A *spurious rainbow* is often seen within the primary rainbow, as shown at $p\,q$, fig. 480. This is formed by the second bright band of each color, the position and intensity of which is represented at b, fig. 479. A third and fourth bow are also sometimes seen, still interior to the second, but the colors of the third and fourth orders are so far mingled that only two or three appear in any bow interior to the first spurious bow.

841. **Fog-bows.—Halos.—Coronas.—Parhelia.**—*Fog-bows*, which are sometimes seen, differ from the rainbow by the extreme minuteness of the spherules of water from which the reflection takes place.

Halos around the sun are sometimes seen, of 45° and 92° diameter: these are explained by reflection from minute crystals of ice floating in the atmosphere.

Coronas, encircling the moon, are formed by reflection from the external surface of watery vapor, the light thus reflected interfering with direct light from the same source.

What is the relative order of colors in the secondary bow? Where and how is the first spurious bow seen? How is the spurious rainbow produced? 841. Why do fog-bows differ from the ordinary rainbow? How are halos produced? How are coronas formed? What are parhelia?

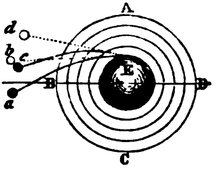
Parhelia, and bands of light passing through the sun, are also attributed to reflection from prisms of ice.

Many of these phenomena require for their explanation a refinement of investigation not proper to be introduced in an elementary work.

842. **Atmospheric refraction** causes all bodies not directly in the zenith to appear more elevated than they really are.

Let *A B C D*, fig. 481, represent the external surface of the atmosphere, and the inner circles strata of increasing density around the earth, *E*. Light from any of the heavenly bodies situated at *a* or *c* will suffer refraction by every strata of air more dense than the preceding, or by a gradually increasing density, it will be made to travel in curved lines, until entering the eye of the observer, the bodies at *a* and *c* will appear situated at *b* and *d*.

481

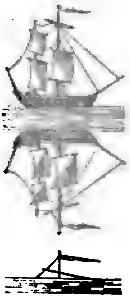


843. **Looming** is a term applied to the elevation of objects at sea which appear elevated above their real position by atmospheric refraction.

Islands often appear thus raised above the water, and an inverted image is seen below them. Distant vessels sometimes appear above the horizon, when their distance is so great they would be far below the horizon if they were not elevated in appearance by extraordinary refraction.

In peculiar states of the atmosphere, ships have appeared suspended in the clouds, and occasionally an inverted image below them, when the real ship was mostly below the horizon, as shown in fig 482.

482



844. **The mirage,** often seen in Egypt, and other sandy deserts, is caused by rays reflected from strata of air heated by the burning sands. Distant objects are seen reflected by the heated air, as in the waters of a beautiful lake, which disappears as the thirsty traveller approaches. The phenomena of the mirage are shown in fig. 483.

845. **Colors of grooved plates.**—Fine lines engraved upon

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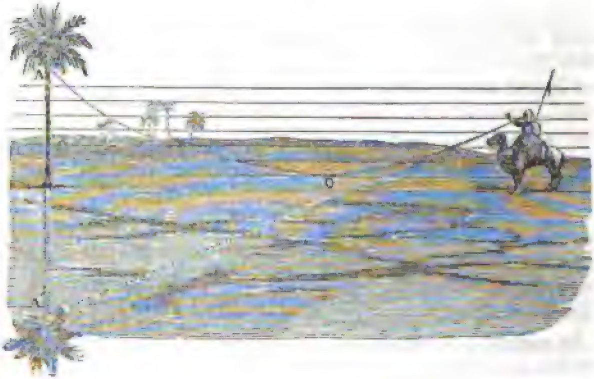
842. What effect does the atmosphere have upon the apparent position of the heavenly bodies? 843. Explain the phenomena called looming. 844. How is the mirage produced?

polished steel, and lines drawn upon glass with a diamond point, if sufficiently near together, cause a beautiful irridescence by the interference of light reflected from such surfaces. The beautiful play of colors seen upon mother of pearl is caused by the delicate veins with which the surface is covered.

483



846. **Fluorescence.—Epipolic dispersion.**—Certain bodies, as fluor-spar, glass colored yellow by oxide of uranium, called *canary glass*, solution of sulphate of quinine and infusion of the bark of the horse-chestnut, possess the remarkable property of so dispersing some part of the light passing through them, that the course of the luminous rays becomes visible.

These phenomena are best exhibited by bringing a pencil of light to a focus in the interior of any of these substances, by means of a convex lens, when the course of the rays will become visible, as though the portion through which the light passed had become self-luminous. The rays of light of high refrangibility, especially the violet and the invisible chemical rays, are subject to this kind of dispersion, their refrangibility is at the same time changed, and probably the length of their luminous waves is increased, so that rays previously invisible may be seen by the eye. These phenomena have been called by various names, as internal dispersion, epipolic dispersion, and fluorescence. The latter term, adopted by Mr. Stokes from fluor-spar, is considered the more appropriate term as it involves no theory.

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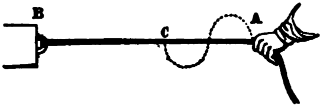
845. How do fine grooves, or lines upon polished surfaces, produce colors? 846. What is meant by fluorescence? From what is the term fluorescence derived?

POLARIZATION OF LIGHT.

847. **Nature of luminous vibrations.**—The phenomena of polarized light are justly regarded as the most wonderful in the whole science of optics. These phenomena are most readily explained and understood by reference to the undulatory theory. It has been stated, (718,) that the vibrations of light move at right angles with the direction of the rays.

This species of vibration may be illustrated by the vibrations of a cord, made fast at one end, and moved rapidly upward and downward by the hand shaking the other extremity, as shown in fig. 484. If we suppose another cord vibrating from right to left, and others in every intermediate direction, we may form a tolerably clear idea of the vibrations of a collection of rays in a beam of ordinary light. A single luminous atom may be supposed to originate vibrations moving in only a single plane, but an infinite number of independent luminous atoms, constituting a luminous body, will produce vibrations moving in every possible plane, which may be represented by revolving that plane, around the line representing the direction of a ray of common light.

484



848. **Transmission of luminous vibrations.**—Opaque substances allow no luminous vibrations to pass through them. Some bodies transmit nearly all the luminous vibrations which fall upon them; other bodies are capable of transmitting only those vibrations of light contained in a single plane, or that portion of the vibrating force which can be resolved into vibrations in that plane. Other bodies, capable of vibrating in two directions, reduce all the vibrations which they transmit to vibrations in the two planes in which these bodies themselves are capable of vibrating. Some bodies, by reason of the position in which an incident beam of light falls upon them, alter the direction of the vibrations which they transmit, and thus produce a beam of light, whose vibrations are all limited to a single plane.

849. **Change produced by polarization of light.**—A beam of light is said to be polarized when all its vibrations move in a

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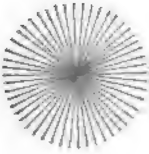
847. What theory of light affords the readiest method of explaining the polarization of light? Explain the nature of luminous vibrations according to the undulatory theory. 848. How do bodies differ in regard to the transmission of luminous vibrations? 849. What change does polarization produce in a beam of light?

single plane, or in planes parallel to each other. This may be illustrated by a bundle of stretched cords, all vibrating in one direction. If the cords differ in size or tension, the length of their vibrations will differ. This may illustrate the vibrations of different colors, which vary in the length of their vibrations.

485



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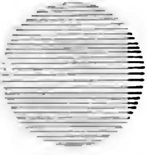

(838.) A round rod may be taken to represent a small beam of common light, and the radii shown in fig. 485 may represent the transverse vibrations by which light is propagated in ordinary media. Fig. 486 will then represent a transverse section of a polarized beam, with vibrations in planes parallel to each other.

850. **Resolution of vibrations.**—The principle of resolution of forces, (110,) will enable us to understand how vibrations, in an infinite number of planes passing through the general direction of a beam of light, may be resolved into vibrations in two planes, making with each other any required angle. If $O E$, fig. 487, represents the direction and intensity of a vibration it will be equivalent to $O a$ and $O c$, in axes, at right angles to each other. Vibrations represented by $O F$, $O G$, and $O H$, may, in the same manner, be resolved into vibrations in the axes $A B$ and $C D$. Then $O a + O a' + O b + O b'$, will represent the intensity of the resulting vibrations in the axis $A B$, and $O c + O c' + O d + O d'$, will represent the intensity of the resulting vibrations in the axis $C D$. If we thus resolve vibrations in an infinite number of planes into vibrations in the axes $A B$ and $C D$, the sum of the resulting intensities in the axis $A B$, will be exactly equal to the sum of the intensities in the axis $C D$. A ray of common light may therefore be considered as consisting of vibrations moving in two planes at right angles to each other. Any medium that will, either by its position or internal constitution, separate light into

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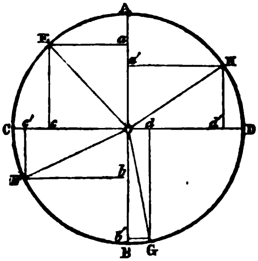

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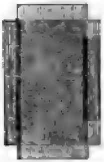
850. On what principle can we explain the resolution of vibrations in any number of planes into vibrations in two planes at right angles with each other? To what may the vibrations of a ray of ordinary light be considered equivalent? When is a medium said to polarize light?

two parts, vibrating in planes at right angles to each other, will produce that change denominated polarization of light.

851. Light polarized by absorption.—Certain crystals have the remarkable property of polarizing all the light which passes through them in particular directions. They appear to absorb part of the light, and cause the remainder to vibrate in a single direction only.

If a transparent tourmaline is cut into plates one-thirtieth of an inch thick and polished, the plane of section being parallel to the vertical axis of the hexagonal prism in which this mineral crystallizes, the light transmitted through such a plate will be polarized. If a second plate is placed parallel to the first, as shown in fig. 488, the light transmitted through the first plate, will also be transmitted through the second plate; but the light will be entirely obstructed if the axis of the second plate is placed at right angles with that of the first, as shown in fig. 489. A plate of tourmaline becomes, therefore, a convenient means of polarizing light, and also an instrument for determining whether a ray of light has been polarized by other means. A tourmaline plate so used, is called an analyzer. Crystalline plates of sulphate of iodo-quinine, (called Herapathite, from the name of their discoverer, Mr. Herapath,) act in all respects like plates of tourmaline.

488



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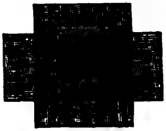

852. Polarization by reflection.—When light falls upon a transparent medium, at any angle of incidence whatever, some portion of the light is reflected. When the incident light falls upon the medium at a particular angle, which varies with the nature of the substance, all the reflected light is polarized.

Let *G*, *G*, fig. 490, be a plate of glass, or any other transparent medium, and let a ray of light, *a b*, fall upon it at such an angle that the reflected ray *b c*, shall make an angle of 90° with the refracted ray, *b d*, then the reflected ray *b c*, which represents but a small portion of the incident light, will be polarized. If the medium is bounded by parallel surfaces, the portion of the light reflected from the second surface, will also be polarized.

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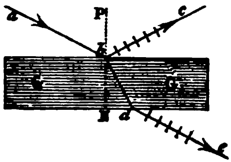
851. How are plates of tourmaline prepared for polarizing light? How does light transmitted through a plate of tourmaline differ from common light? What is meant by an analyzer? 852. How may light be polarized by reflection?

490



The angle of polarization by reflection may be determined by the following law. *The tanget of the angle of incidence for which the reflected ray is polarized, is equal to the index of refraction for the reflecting medium.* This law supposes the reflecting substance more dense than the surrounding medium. If the light is reflected from the second surface, as when passing from glass or water into air; *the index of refraction equals the cotangent of the angle of polarization.* The polarizing angle for reflection from glass, is 56° 25′, reckoned from the perpendicular. The polarizing angle for water, is 53° 11′. As the index of refraction varies for different colors, the polarizing angle varies in the same manner.

If a polarized ray falls upon a reflecting surface at the angle of polarization, and the reflecting surface is rotated around the polarized ray as an axis, when it is so placed that the plane of incidence corresponds with the plane in which the ray was polarized, the polarized light will be reflected just as if it were not polarized; but when the plane of incidence makes an angle of 90° with the plane of polarization, the light is entirely intercepted. In this respect a reflecting surface, at the proper angle of incidence, serves the purpose of an analyzer, just like a plate of tourmaline.

853. **Polarization by refraction.**—When light is polarized by reflection from either the first or the second surface of a transparent medium, a portion of the transmitted light is polarized by refraction. The amount of light polarized by refraction is just equal to the amount polarized by reflection, but as the amount of light transmitted by transparent substances, very much exceeds the amount reflected from their surfaces, only a small portion of the transmitted rays are polarized, or, more properly, the light transmitted through a single plate is but *partially polarized.*

854. **Polarization by successive refractions.**—If a ray of light, *R R′* is transmitted obliquely through a number of parallel transparent plates, as shown in fig. 491, a portion of the light is polarized at every refraction, and after a sufficient number of refractions, the whole of the transmitted light is polarized.

Light polarized by refraction, is polarized in a plane at right an-

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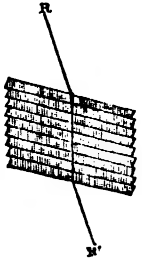
What is the rule for determining the angle of polarization by reflection from the first surface? What is the rule for the second surface? What is the polarizing angle for glass? For water? In what circumstances can a ray of light polarized by reflection be again reflected? 853. How is light polarized by refraction?

gles with the plane of polarization by reflection. Light polarized by reflection vibrates at right angles with its plane of polarization, or its plane of reflection, as shown at *B*, fig. 492.

491



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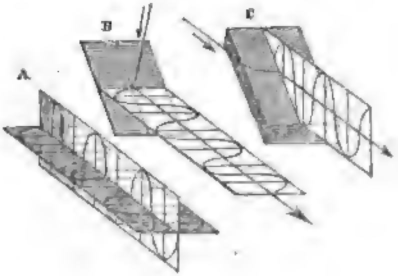
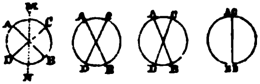


Light polarized by refraction, vibrates also at right angles with its plane of polarization, but parallel to its plane of refraction, as shown at *C*, fig. 492. Light not polarized, though vibrating in an infinite number of planes, is equivalent to a system of vibrations in two planes at right angles to each other, as shown at *A*, fig. 492.

855. **Partial polarization.**—Light reflected or refracted at any oblique angle is, in general, partially polarized, and by repeated reflections or refractions, the degree of polarization is increased, until, after a sufficient number of reflections or refractions, it is apparently completely polarized.

Let *M N*, fig. 493, represent the plane of refraction, and *A B*, *C D*, the axes of vibration for common light, then by repeated refractions these axes will be gradually made to approach each other, until they sensibly coincide, as shown in the figure, when the light is said to be completely polarized. The portion of light reflected, undergoes a similar series of changes, until the axes of vibration sensibly coincide, in a plane at right angles to their position in light polarized by refraction.

493



856. **Double refraction** is a property in certain crystals that causes the light passing through them in particular directions, to be separated into two portions, which pursue different paths,

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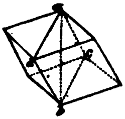
854. How is light polarized by successive refractions? How do the vibrations of light polarized by reflection differ from the vibrations of light polarized by refraction at the same surface? 855. What is meant by partial polarization? 856. What is meant by double refraction? What is the major axis in a crystal of Iceland spar?

and which causes objects seen through the crystals to appear double.

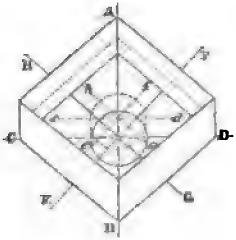
The most remarkable substance of this kind with which we are familiar, is Iceland spar, or carbonate of lime, which crystallizes in the rhombic system, as shown in fig. 494. The line *a b*, about which all its faces are symmetrically arranged, is called the major axis of the crystal, and the plane *a c b d*, passing through the axis, and through the obtuse lateral edges, is called the ***plane of principal section.*** (59.)

494



If a crystal of Iceland spar, from half an inch, upwards, in thickness, is laid upon a sheet of paper, on which are drawn various lines, they will appear double, as shown in fig. 495. *A B*, *C D*, *E F*, *G H*, are the real lines, seen in their true positions. The dotted lines show the position of the additional lines, caused by extraordinary refraction. The line *A B*, in the plane of principal section, is not doubled. Any line parallel to *A B*, will also appear single. The index of refraction for the ordinary ray remains constant, in whatever direction light passes through the crystal. The index of refraction for the extraordinary ray, when parallel to the axis, is the same as that of the ordinary ray, and differs most from the ordinary ray when it passes through the crystal at right angles with the axis.

495



The index of refraction for the ordinary ray in Iceland spar is constantly 1,6543 = *m*. The index of refraction for the ordinary ray, when it makes an angle of 90° with the major axis, is 1,4833 = *n*. Let x = the angle which the extraordinary ray makes with the major axis in any other position; and let N = the corresponding index of refraction for the extraordinary ray, its value may be determined by the following formula:

$$N = \sqrt{m^2 + (n^2 - m^2) \sin^2 x} = \sqrt{2,7367 - 0.5365 \sin^2 x}.$$

857. **Positive and negative crystals.**—*Positive crystals* are those in which the index of refraction for the extraordinary ray

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How do lines appear when seen through a natural face in a crystal of Iceland spar? In what position will a line appear single? What is meant by the extraordinary ray? In what direction must the extraordinary ray pass through the crystal, to diverge most widely from the ordinary ray?

is greater than for the ordinary ray, and the extraordinary ray is refracted nearer to the axis than the ordinary ray. Quartz and ice are examples of this class.

Negative crystals are such as have the index of refraction for the extraordinary ray less than for the ordinary ray, the extraordinary ray being refracted farther from the axis than the ordinary ray. Iceland spar, tourmaline, corundum, sapphire, and mica, are examples of negative crystals.

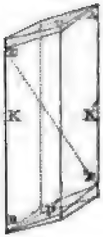
Some crystals have two axes of double refraction, as nitrate of potash, sulphate of barytes, and some varieties of mica.

858. **Polarization by double refraction.**—When the light transmitted through a doubly refracting substance is examined with an analyzer, it is found that both the ordinary and extraordinary rays are completely polarized, whatever be the color of the light employed. The tourmaline plate, or other analyzer, will, in one position, transmit the ordinary image and wholly intercept the other, but when the tourmaline has been rotated 90°, the ordinary ray is intercepted, and the extraordinary ray is transmitted.

859. **Nicol's single image prism** is an instrument formed of Iceland spar, by which the ordinary image, produced by double refraction, is thrown out of the field, and only a single image, (the extraordinary,) is transmitted.

An elongated prism of Iceland spar is cut through by a plane, *E F*, at right angles with the principal section, from the obtuse solid angle *E*, fig. 496, making an angle of 22°, with the obtuse lateral edge *K*. The terminal face, *P*, is ground away, so as to make an angle of 68° with the obtuse lateral edge, and the opposite face, *P'*, is ground in the same manner. All the new faces are carefully polished, and the two parts are cemented together again with Canada balsam, in the same position they previously occupied. The lateral faces of this compound prism are all painted black, leaving only the terminal faces for the transmission of light.

496



When a ray of light, *a b*, fig. 497, falls upon this prism, it is refracted into the ordinary ray *b c*, and the extraordinary ray *b d*. The

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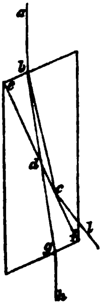
857. Explain the difference between positive and negative crystals. What substances have two axes of double refraction? 858. How do the two rays of light polarized by double refraction differ from each other? 859. How is Nicol's prism constructed? Explain the action of Nicol's prism.

index of refraction of Iceland spar, for the ordinary ray, being 1.654, and that of balsam only 1.536, the ordinary ray cannot pass through the balsam, unless the incident ray diverges widely from the axis of the prism, but it suffers total reflection, and is absorbed by the blackened side of the prism The extraordinary ray has a refractive index in the Iceland spar generally less than in the balsam, varying, for Nicol's prism, between 1·5 and 1·56; therefore it passes through the balsam into the lower part of the prism, and emerges in the direction *g h*, parallel to the incident ray.

These prisms are capable of transmitting a colorless pencil of light, perfectly polarized, from 20° to 27° in breadth.

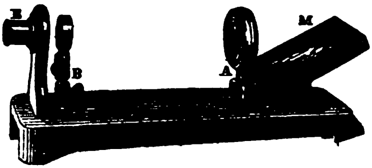
497



860. **Polarizing instruments** are made in a variety of forms, to suit particular purposes. A simple instrument, and yet one of the most convenient in use for exhibiting the phenomena of polarized light, is shown in fig 498.

A mirror, *M*, made of plate glass, covered with black varnish or cloth on the back, or, better, a bundle of ten to twenty thin plates of polished glass, is mounted on a mahogany support at the polarizing angle. A Nicol's prism, or a tourmaline plate, at *E*, serves as an analyzer. The objects to be examined are mounted in discs of wood or cork, and supported at *A* or *B*, where they are most distinctly seen by the eye, looking through the analyzer. The student who has not a tourmaline, or a Nicol's prism, can use as an analyzer a small piece of plate glass, mounted so as to rotate on an axis parallel to the base of the instrument.

498



Polarized light may be applied to the microscope, by mounting a Nicol's prism beneath the stage as a polarizer, and another for an analyzer, in the body of the microscope, above the object glass.

861. **Colored polarization.**—When a thin plate of selenite, mica, or any other doubly refracting substance is placed between the polarizer and the analyzer in the polariscope, the light is

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860. How can a simple and convenient polarizing instrument be constructed? How can polarized light be applied to investigations with the microscope? 861. Describe the phenomena of colored polarization.

separated into two beams, which follow different paths, and as the vibrations of one ray are more retarded than those of the other, when they are reunited, they interfere, and produce the most beautiful colors, varying with the thickness of the plates, and the position of their axes with reference to the axes of the polarizer and the analyzer.

If the film is rotated, while the polarizer and analyzer remain fixed, the color will appear at every quadrant of revolution, and disappear in intermediate positions. If the film and the polarizer remain fixed, and the analyzer is rotated, the color will change to the complementary at every quadrant of revolution; that is, the same color will be seen in positions of the analyzer differing 180°, and the complementary color will be seen at 90° and 270°, from the first position.

Films of selenite, varying between ,00124 and ,01818 of an inch in thickness, will give all the colors between the white of Newton's first order, and white resulting from the mixture of all the colors. If two films of selenite are placed over each other, with their axes parallel, the color produced will be that which belongs to the sum of their thicknesses. But when the two films are placed with their axes at right angles, the resulting tint is that which belongs to the difference of their thicknesses.

862. **Rotatory polarization** is a property which some substances possess of changing the plane of vibration in a ray of polarized light, even when it falls perpendicularly upon it. The entire amount of rotation depends upon the thickness of the medium. Quartz, cut transversely to its major axis, solution of sugar, camphor in the solid state, and most of the essential oils, possess the power of rotating the plane of polarization of a ray passing through them.

Different substances, and sometimes different specimens of the same substance, rotate the plane of polarization in contrary directions. When the rotation takes place in the direction of the motion of the hands of a watch, the medium is said to have right-handed polarization. Thus we have right-handed quartz, and left-handed quartz.

In a beam of white light, the vibrations which produce red have their plane of polarization rotated much more than the colors of greater refrangibility. This property varies inversely as the squares of the lengths of the luminous waves which produce the several co-

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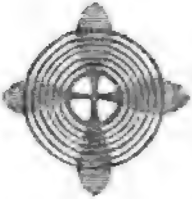
How is the color affected by rotating the film of selenite, while the polarizer and analyzer remain fixed? How does the color change by rotating only the analyzer? What effect is produced by placing one film of selenite over another? 862. Explain the phenomena called rotatory polarization.

lors. The power of rotating the plane of polarization becomes a valuable test for speedily determining the nature of various chemical substances, or the strength of a solution of any substance having this power. Soliel's saccharimiter, for measuring the relative amount of cane and grape sugar in solutions or syrups, is constructed on this principle. Such an instrument affords also a ready method of detecting the presence of sugar in diabetic urine.

863. **Colored rings in crystals.**—Colored rings, with a black cross of great beauty, are seen in thin plates of doubly refracting crystals, when viewed in certain directions, with polarized light.

Figs. 499, and 500, show the appearance of the rings and cross in thick plates of quartz, in positions at 90° from each other. Other uniaxial crystals show a similar system of rings beautifully colored.

499



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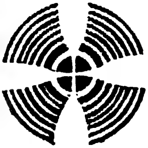

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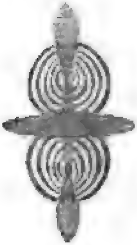

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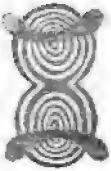

Figs. 501, and 502, show the form of the colored rings in biaxial crystals; *e. g.* some micas. Every doubly refracting crystal presents some peculiarity in the form and arrangement of the colored rings seen in its thin sections. This subject is of great interest to the mineralogist.

864. **Polarization by heat, and by compression.**—Glass irregularly heated, or heated and irregularly cooled, possesses the power of double refraction, and when viewed by polarized light, it exhibits dark crosses, bands, or rings, varying with the form of the glass, and difference of density in different parts. Similar phenomena may be produced by compression, or by bending rods or plates of glass.

865. **Magnetic rotatory polarization.**—If a thick plate of glass is applied to the poles of a powerful electro-magnet, the glass is neither attracted nor repelled; but if a ray of polarized light is transmitted through the plate in a certain direction, the plane of polarization is rotated as by a plate of quartz, or other rotatory

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To what practical purposes may rotatory polarization be applied? 863. What phenomena are seen in certain crystals when viewed by polarized light?

polarizer, showing that light and magnetism have some intimate relation to each other.

This rotatory effect may depend upon change in the tension of the molecules of the glass by the magnetic force, and not upon any direct relation between light and magnetism.

866. **Atmospheric polarization of light.**—The light of the sun reflected by the atmosphere is more or less polarized, depending upon the angular distance from the sun.

If the earth had no atmosphere, the sky would everywhere appear perfectly black. The color of the sky is produced by light reflected by the atmosphere. If we look at the sky through a Nicol's prism, we shall find, on rotating the prism, that light from some parts of the sky is polarized to a very appreciable extent. There are several points in the sky where no polarization is perceptible. The point in the heavens directly opposite to the sun, is called the ***anti-solar point.*** At a distance above the anti-solar point, varying from 11° to 18°, there is a point of no polarization, and another neutral point at an equal distance below the anti solar point. Another neutral point, or point of no polarization, is found from 12° to 18° above the sun, and a similar one below it, but the latter is observed with great difficulty. When the sun is in the zenith, these two points coincide in the sun. At all other points in the sky, the light is more or less polarized, the degree of polarization amounting sometimes to more than one-half as much as by reflection from glass at the angle of complete polarization.

867. **The eye a polariscope.**—The structure of the crystalline lens is such, that the unaided eye is capable of analyzing a beam of light polarized by reflection or by double refraction. A person accustomed to use his eyes in viewing the phenomena of polarization, can thus detect with ease facts of this nature, which are wholly inscrutible to one not familiar with such observations; another of the numerous proofs we have that the eye is capable of very exact training; but nevertheless it is a proof also of an imperfection in the eye itself.

868. **The practical applications of polarized light** are numerous. The *water telescope* consists of an ordinary marine telescope, with a Nicol's prism inserted in the eye-piece.

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864. How may a polarizing structure be produced artificially? 865. How can magnetism be made to affect a ray of light? 866. How does the light of the sky differ from the direct light of the sun? What is the anti-solar point? What points in the sky exhibit no polarization of light? What is the maximum of atmospheric polarization?

The light reflected from the surface of the water is the principal obstruction to viewing objects beneath its surface. Nicol's prism, in a certain position, entirely cuts off the polarized portion of the reflected light, and allows objects far below the surface to be seen in the telescope. A Nicol's prism, in the same manner, will enable the fisherman to direct his spear with greater certainty.

Amateurs, in visiting galleries of paintings, find Nicol's prisms mounted as spectacles, of great service. Let the observer place himself in an oblique position, and look at an oil painting; when the sheen of reflected light renders the objects in the painting invisible, he has but to look through a Nicol's prism, set in a proper position, and the entire details of the painting at once become visible in all their proper colors. An opera-glass, provided with Nicol's prisms, would be a valuable instrument in examining a picture gallery. Polarized light is also of great value in microscopic investigations.

503

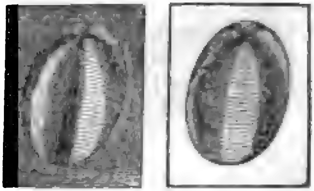

Fig. 503 shows the appearance of a grain of starch, seen in the microscope with polarized light. The dark cross which changes its position by rotating the analyzer, distinguishes starch from every other substance. Different kinds of starch are also thus readily distinguished from each other.

By means of polarized light, the chemist can detect one thirteen-millionth of a grain of soda, and distinguish it from potassa or any other alkali. In physiological chemistry, especially in the examination of crystals found in various cavities and fluids of both animals and plants, the use of polarized light is especially important.

Instead of a few isolated facts, of interest only to the curious inquiirer, the polarization of light presents itself as a great fact in nature, meeting us with wonderful revelations in almost every department of natural science. By this marvelous property of light, the astronomer determines that the planets shine by reflected light, and that the stars are self-luminous bodies.

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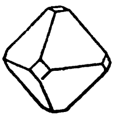
867. What evidence is there that the human eye is a polariscope? 868. What is the peculiarity of the water telescope? What effect is produced by looking obliquely at an oil painting through a Nicol's prism? What peculiar appearance is observed in grains of starch when examined in the microscope by polarized light? What facts in chemistry and astronomy show the practical application of polarized light?

MAGNETISM.

PROPERTIES OF MAGNETS.

869. **Lodestone—natural magnets.**—There is an ore of iron, called by mineralogists magnetite, or magnetic iron, some specimens of which possess the power of attracting to themselves small fragments of a like kind, or of metallic iron. This power has been called *magnetism*, from the name of the ancient city of Magnesia, in Lydia, (Asia Minor,) near which the ore spoken of was first found. It crystallizes in forms of the monometric system, often modified octohedra, like fig. 504, and is a compound of one equivalent of peroxyd of iron with one of protoxyd. ($FeO + Fe_2O_3 = Fe_3O_4$.) It is one of the best ores of this valuable metal.

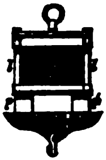
504



All magnets were originally lodestones, or natural magnets. A fragment of this ore rolled in iron filings or magnetic sand, becomes tufted, as in fig. 505, not alike in all parts, but chiefly at the ends. Fig. 506 shows the same mass mounted in a frame of soft iron, *l l*, with poles, *p p'*. Thus mounted, the lodestone gains in strength, by sustaining a weight from the hook below, on a soft iron cross bar.

505

506



870. **Artificial magnets** are made by touch or influence from a lodestone, or from another magnet, or by an electrical current. Hardened steel is found to retain this influence permanently, while masses of soft iron become magnets only when in contact with, or within a certain distance of a permanent magnet. Artificial magnets are more powerful than the lodestone, and possess properties entirely identical with it. Magnets attract at all distances, but their power increases, like all forces acting from a centre, inversely as the square of the distance. Heat diminishes the power of magnets, but if not heated beyond a certain degree, 1400° F., (full redness,) this power returns on cooling, and is increased at lower temperatures. Above that point, the coercive power, (881,) is destroyed, and they lose all sensibility to magnetic influence.

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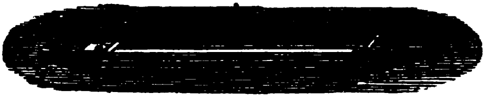
869. What is the lodestone? Whence the term magnetism? What is said of natural magnets? How is their power distributed? How are they mounted? 870. How are artificial magnets made? What is said of the power of magnets?

Various forms are given to magnets. The *bar magnet* is a simple straight bar of hardened steel. If curved so as to bring the ends near together, it is called a *horse shoe* magnet, and if several bars, straight or curved, are bound together into one, fig. 507, it is called a compound magnet, or magnetic battery.

507



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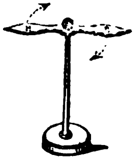
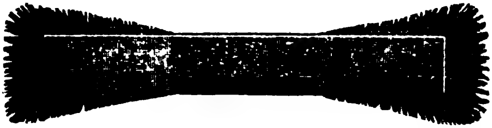


Magnetic needles are light bars, fig. 508, suspended on a central point so as to move in obedience to terrestrial or artificial attractions. The mode of making magnets, and the circumstances influencing their power, are noticed hereafter. The most powerful artificial magnets can sustain only about twenty-eight or thirty times their own weight. Usually they sustain very much less.

871. **Distribution of the magnetic force—polarity.**—The magnetic force is not equally distributed in all parts of a magnet, but is found concentrated chiefly about the ends, and diminishing toward the centre, which is neutral. The points of greatest attraction are called poles. When a magnet is rolled in iron filings or magnetic sand, the position of the poles is seen as in the bar magnet, fig. 509, whose centre is found to be quite devoid of the attracted particles which cluster about the ends. The point of no attraction is called the neutral point—line of magnetic indifference, or equator of magnetism. Every magnet has at least two poles, and one neutral point. The magnetic poles are distinguished as N or S, austral or boreal, (*A* and *B*,) or by the signs, (+) and minus, (—) all these signs having reference to the earth's attraction, and to the antagonism between the poles of unlike

509



How does heat affect it? Name the several sorts of artificial magnets? 871. How is the magnetic force distributed? What are the poles? What is the neutral point? How are poles marked?

name. The law regulating the distribution of magnetic force in a bar, was determined by Coulomb, by means of the torsion balance, to be very nearly as the squares of the distance of any given point, from the magnetic equator or neutral point.

872. **Magnetic phantom—magnetic curves.**—The distribution of the magnetic force about the poles of a magnet is beautifully shown by placing a sheet of stiff paper over the poles of a horseshoe magnet, and scattering fine iron filings or magnetic sand from a seive or gauze bag over the paper. As they touch the surface of the paper, each filing assumes a certain position, marking the exact place of the magnetic poles and of the neutral line, as seen in fig. 510. The magnet may be laid horizontally, or a series of magnetic bars may be placed as in fig. 515, producing very pleasing and instructive results. Tapping the edge of the paper gently with the nail, or a pen-stick, facilitates the adjustment of the filings. The curves exhibited by the magnetic phantom have been mathematically investigated by De Haldat, who for that purpose transferred them to a glued paper.

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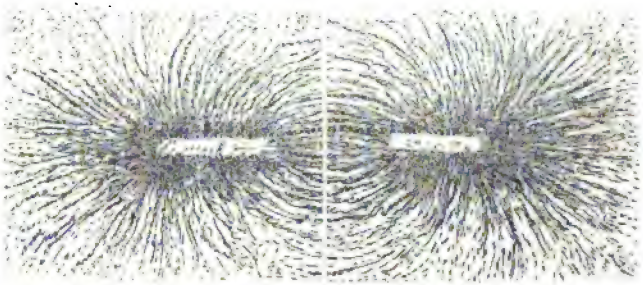

873. **Magnetic figures** may be produced on the surface of a thin steel plate, by marking on it with one pole of a bar magnet. Magnetism is thus produced in the steel along the line of contact, which is afterwards made evident by magnetic sand, or iron filings sprinkled on the plate. These lines may be varied or multiplied at pleasure, with pleasing effects; their polarity is always the reverse of that carried by the bar. They may be made even through paper or card board, and will remain for a long time. Blows, or heat,

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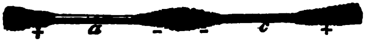
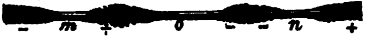
What law regulates the distribution of magnetism? 872. What is the magnetic phantom? How are the magnetic curves shown and preserved? 873. What are magnetic figures, and how produced? What is their polarity? What shows them best?

will remove them. Hard plate steel is best for this purpose, about one-twentieth to one-eighth of an inch thick, and six inches to twelve inches square.

874. **Anomalous magnets** are such as have more than *two* poles. Thus the bar seen in fig. 511, has a pair of similar poles. (—) at the centre, and its ends are of course also similar, (+) while it has two neutral points at *a* and *c*. Fig. 512, shows a bar with three sets of poles, arranged alternately — and +, with three neutral points at *m*, *o*, and *n*. Broken at these neutral points, every magnet becomes two or more separate magnets, with corresponding polarity.

511



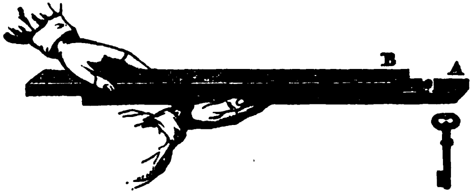


512

875. **Attraction and repulsion.**—The law of magnetic attraction and repulsion is, that *like poles repel, and unlike poles attract each other.*

If a piece of soft iron is presented to either pole of a magnetic needle, fig. 508, there is attraction, which is reciprocal between the needle and the iron; for if the iron is suspended, and the needle approached to it, the iron is attracted by either end of the needle. If, however, a magnet is approached to the needle, + to — there is attraction; if — to — or + to + there is repulsion.

513



If the unlike poles of two equal magnetic bars, tufted with iron-filings, are approached, the tufts join in a festoon; but if the poles are of the same name, most of the filings fall. For the same reason, if a magnetic bar, *B*, fig. 513, is slid upon another bar, *A*, of equal power to *B*, as the two opposite ends approach each other, the key, previously suspended, falls, because the two bars mutually neutralize each other by the opposing action of the austral and boreal magnetism.

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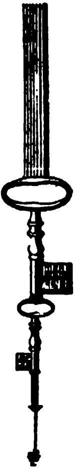
874. What are anomalous magnets? Describe figs. 511 and 512.
875. What is the law of magnetic attraction and repulsion? How is it with soft iron? Explain the experiment shown in fig. 513.

876. **Magnetism by contact.**—When a mass of iron, or of any magnetizable body is placed in contact with a magnet, it receives throughout its mass magnetism, of the same name as the pole with which it is in contact. Thus in fig. 514, the key is sustained by the north pole of a magnetic bar; a second key, a nail, a tack, and some iron-filings, are, in succession, also sustained by the magnetism imparted by contact from the bar magnet through the soft iron. Tested by a delicate needle, every part of the sustained masses will manifest only north polarity, and we may regard them as only prolongations of the original pole. This is analogous to electrical conduction.

Pure soft iron receives magnetism sooner and more powerfully than steel or cast-iron, and also parts with it sooner. Hardened steel and hard cast-iron, retain more or less of the magnetic force permanently. No other metals beside iron, nickel, cobalt, and possibly manganese, can receive or retain magnetism by contact. These are therefore called the magnetic metals.

514



877. **Magnetism in bodies not ferruginous.**—Beside the magnetic metals, so-called, Cavallo has shown that the alloy, brass, becomes magnetic (slightly) by hammering, but loses that property again by heat. Some minerals are magnetic, particularly when they have been heated. The pure earths, and even silica, are found to have the same property. In the case of silica, and some other minerals containing oxyd of iron in combination, this is not so surprising. M. Biot determined in the case of two specimens of mica, one from Siberia, (muscovite,) and the other from Zinnwald, (lithia mica,) that their magnetic powers were, (by the method of oscillations,) as 6·8, to 20, and he remarked, if the oxyd of iron be the cause of their magnetic virtue, it should exist in the minerals in the above proportion; and curiously enough, the result of Vauquelin's analyses, (then unknown to M. Biot,) corresponded, almost exactly, to these numbers.

Some states of chemical combination, however, appear to destroy, or cloak, the magnetic virtues of iron; *e. g.* an alloy of iron, one part,

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876. Illustrate magnetism by contact, from fig. 514. What is the polarity of the mass in contact? Compare soft iron and hardened steel in respect to magnetic power. What other metals receive magnetism? 877. What other bodies does Cavallo state to be magnetic? What was Biot's observation on mica? Where is the magnetic virtue of iron cloaked?

with antimony four parts, was found by Seebeck to be utterly devoid of magnetic action; and the magnetic power of nickel is entirely concealed in the alloy called German silver.

MAGNETIC INDUCTION OR INFLUENCE.

878. **Induction.**—Every magnet is surrounded by a sphere of magnetic influence, which has been called its magnetic atmosphere. Every magnetizable substance within this influence becomes magnetic also, (without contact,) the parts contiguous to the magnet pole, having an opposite, and those remote from it, a similar name. This influence is called *induction.*

Thus in fig. 515, the *N* end of a bar magnet induces south polarity in the contiguous ends of the five bars surrounding it, and *N* polarity in their remote ends. If these bars are of hardened steel, they will retain a small portion of the magnetic force induced from a powerful bar, but if they are of soft iron, they will part with it as soon as the source of magnetism is withdrawn. In this case, the magnetized bars have a tendency to move up to the magnet, and are prevented only by friction and gravity. The attraction is reciprocal, and we hence infer that there is induction in every case of magnetic attraction.

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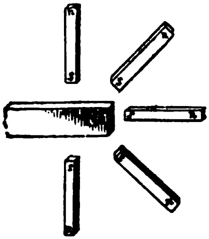

In the iron-filings, arranged in magnetic curves, fig. 510, on a glass plate, or card board, the same law is observed.

Small pieces of soft iron wire suspended from the ends of a thread near, and parallel to each other, when approached by a bar magnet, receive induced magnetism, the farther ends diverging by mutual repulsion. Two sewing needles thus suspended and influenced, become permanent magnets.

The ingenuity of the teacher, aided by such familiar works as 'Davis' Manual of Magnetism,' or 'Harris' Rudiments,' will furnish many pleasing and instructive illustrations of magnetic induction.

879. **Theoretical considerations.**—The real nature of the magnetic force is unknown to us; but the analogies offered by electro-magnetism and magneto-electricity, lead to the conviction

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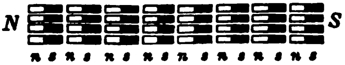
878. What influence surrounds a magnet? What is this power called? Illustrate it by fig. 515. Give other illustrations. 879. What is said of the analogies of magnetic force? How is it concentrated with other forces? 880. What is the theory of two magnetic fluids?

that it is but one mode of electrical excitement. Magnetism affords no phenomena immediately addressed to the senses, unlike the case of light, heat, and statical electricity. It is distinguished from statical electricity by its permanent character when once excited, and by the very limited number of substances capable of receiving and manifesting it.

880. **Theory of two fluids.**—It may be assumed that there are two magnetic or electrical fluids, (the boreal or positive, and the austral or negative,) which are in a state of equilibrium or combination in all bodies; that in iron, nickel, &c., these two forces are capable of separation, by virtue of the inductive influence of the earth, or of another magnet, while in other bodies, this permanent separation cannot be effected. The two magnetic forces are never seen isolated from each other, but are always united in one bar. Hence we cannot have a boreal magnet, or an austral magnet, as we may in statical electricity produce, at pleasure, vitreous or resinous excitement over the whole surface of a body. Both names must co-exist, and if we break a magnetic bar at its neutral point, we have two magnets of diminished force, but each half has its two poles like the original bar, and its neutral point also. The *anomalous* magnets, figs. 511, 512, will render this statement intelligible. Every magnet must, in this view, be regarded as an assemblage of numberless small magnets, every molecule of steel having its own poles, antagonistic to those of the next contiguous particle. This conception is rendered more evident by fig. 516. Hence the *N* and *S* poles of the several particles each point in one way, and towards the *N* and *S* ends of the bar. These opposing forces therefore constantly increase from the centre or neutral point, where they are in equilibrium, to the ends, where they find their maximum. This arbitrary explanation enables us to conceive how such a body may excite similar manifestations of power in another, without itself being weakened, and how each part becomes a perfect magnet, if the bar is broken. The experiment shown in fig. 513, illustrates well the re-union of the two fluids, to form the neutral state of the undecomposed influence.

516



What is said of the existence of these? How may every magnet be regarded? Illustrate this from fig. 516. How do iron filings, the magnetic pastes, &c., illustrate it?

De Haldat has shown that a brass tube, filled with iron-filings, confined by screwed caps of brass, can be magnetized by any of the modes used for bars, and have its poles and neutral point like a bar magnet; but if, by concussion, the particles of iron are disarranged, the magnetic force diminishes, and finally disappears.

The magnetic pastes of Dr. Knight, and of Ingenhouz, also illustrate the fact, that little particles of magnetic iron, or of pulverized lodestone, could determine the existence of the magnetic poles, and a neutral line, when they were compacted into a mass, by drying oils, or some gummy substance.

Even so small a quantity as one-sixth of ferruginous particles, in five-sixths of sand or earthy matter, can be magnetized as a bar, showing clearly the decomposition of the neutral fluid in each particle.

881. **Coercive force.**—The resistance which most substances show to the induction of magnetism, has been distinguished by the term *coercive force.* In soft iron, this force may be regarded as at a minimum, since it will receive magnetic induction, even from being placed in the line of magnetic dip, while in steel which has been hardened, it requires a peculiar manipulation to induce any permanent magnetism. Soft iron parts with its induced magnetism as readily as it receives it; but if it is hardened by blows or violent twisting, or by small portions of phosphorus, arsenic, or carbon, combined with it, a portion of magnetism is permanently retained.

As blows, by hardening, may induce permanent magnetism in soft iron, so in steel, the coercive force may, by simple vibration, as by blows on a magnetic bar, or by an accidental fall, destroy a large part of the force developed, by giving opportunity to the coercive force to resume its supremacy. In general, whatever cause induces hardness, increases the coercive force, and conversely it is diminished by annealing, or any cause which results in softening the mass.

TERRESTRIAL MAGNETISM.

882. **Magnetic needle.—Directive tendency.**—A magnetic needle, suspended over the poles of a horse-shoe magnet, comes to rest in the plane of the poles; and in obedience to the fundamental law of magnetic attractions, its *A* and *B* poles will be opposite to the *B* and *A* poles of the attracting magnet. The

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881. What is meant by coercive force? Compare this force in hard and soft iron. How do blows affect it in the two?

suspended needle, in fig. 517, assumes its position by reason of the same law, and comes to rest with its *A* pole toward the *N* pole of the earth, and its *B* pole towards the South. All bar magnets, having a free motion in a horizontal plane, arrange themselves in this manner in every part of the earth.

This directive tendency of the magnet has been known to European nations since the 12th century; but was known, it is said, to the Chinese 2000 B. C. The earliest mariner's compass, used by Syrian navigators in 1242, was a common sewing needle, rendered magnetic, thrust through a reed, or cork, and allowed to float on water. (Klaproth.) This directive power renders the compass invaluable to the explorer of a pathless wilderness, to the surveyor and the miner: the mineralogist and the physicist also find it indispensable in many researches.

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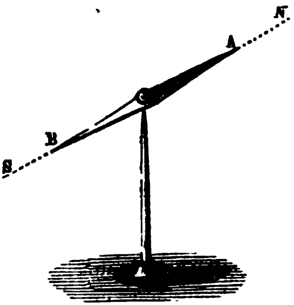

The terms *austral* and *boreal,* have been applied to the polarity of the magnetic needle, in allusion to the free austral and boreal magnetism assumed to exist respectively in the southern and northern regions of the earth. In accordance with magnetic law, the end of the needle pointing north is called *austral*, and that pointing south, *boreal.* For greater simplicity, the mariners' compass is marked N, on that point which turns to the north, and conversely; but the terms austral and boreal may be used interchangeably with positive and negative, or north and south polarity.

The mariners' compass has a card attached to the magnetic bar and is centered, to traverse with it on the point of suspension. This card is divided into thirty-two points, seven between each two of the cardinal points, N. E., S. W. The whole is suspended on gimbalds, or universal joints, in a box conveniently disposed for illumination at night.

The astatic needle is an instrument in which the directive tendency of the earth's magnetism is neutralized, by placing two equal needles, *a b, b' a'*, fig. 518, parallel, one above the other, with their unlike poles opposed to each other. This system is suspended by a fibre of raw

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882. How does a magnetic needle act between the poles of a horseshoe magnet? How towards the earth? Give the history of the needle. How are the terms austral and boreal used? How is the mariners' compass constructed? What is the astatic needle?

silk, and is a most sensitive test for feeble magnetic currents. Such is the construction adopted in the galvaniscope, to be hereafter described. The two needles must be of exactly equal force, or *a b* and *a' b*, will not neutralize each other, and the system will have a directive tendency, equal to any difference of force in the two needles.

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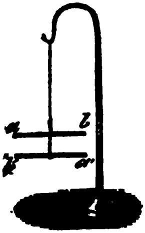

The most simple astatic needle is made by touching a steel sewing needle, at its centre of weight, by the N. pole of a powerful magnet; the point touched develops two S. poles, and the two ends are N. Such a needle is very nearly astatic.

888. **Magnetic meridian—declination or variation.**—There are but few places in the world where the magnetic needle points to the true, or astronomical North, and in all other places, a plane passing through the axis of the magnetic needle, (the magnetic meridian,) fails to coincide with the geographical meridian. Moreover, the magnetic meridian in any given place is not constant, but changes slowly from year to year, (called secular variation,) being now on the E., and again on the W. side of the true North. This is called the *declination* or *variation* of the magnetic needle. The declination is called Eastern, or Western, according as it may be to the East or to the West of the astronomical meridian. The angle formed by the meeting of the true and the magnetic meridians is called the *angle of declination.* Thus, at Washington city, the angle of declination in 1855—6, was 5° 44'· 2 W., and at New Haven it was 6° 37' ·9 W., in 1848—9.

Columbus, in his first voyage to America, found the needle to have, as he sailed westwards, an increasing variation from the true North, a circumstance which caused the greatest consternation in his superstitious crew, "who thought the laws of nature were changing, and that the compass was about to lose its mysterious power." (Irving's Columbus.) Notwithstanding these and other similar observations, it was not until the middle of the 17th century, that the variation of the compass was an established fact in magnetic science. The observations on the declination of the compass in England, date from 1580. The following table, from Harris, contains the declination with the mean rate of motion, as referred to certain periods of ob-

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888. What is said of the magnetic meridian? What is secular variation? What is the angle of declination? What is said of Columbus? Give the changes in England for 270 years. What did Dr. Halley do, and where?

servation in London, between 1580 and 1850, or about two hundred and seventy years

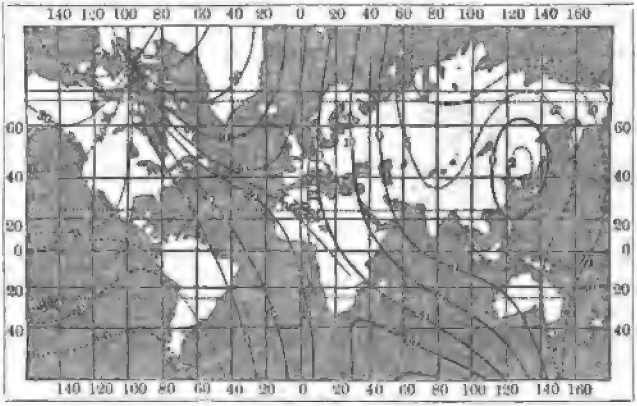
	Eastern Declination.			Zero.		Western Declination.		
Years,	1580.	1622.	1660	1692.	1730.	1765.	1818.	1850.
Declination,	11° 15′	6°	0	6°	13°	20°	24° 41′	22° 30′
Rate per year,	7′	8′	10′	11′	11′·5	9′	0′	5′

Thus in a period of eighty years from the first observation, the needle gradually reached the true meridian, and then for a period of one hundred and fifty-eight years it moved Westward, reaching its maximum Westerly declination in 1818, and it is now again slowly moving Eastwards. The rate of this movement is not uniform, but is greater near the minimum, and least near the maximum, point of declination.

The first attempt to systematize the variations of the magnetic needle, and to connect by lines, called *isogonic* lines, all those places on the earth where the declination was similar, was made by Halley, about 1700. He thus discovered two distinct lines of no inclination, called *agonic* lines, one of which ran obliquely over North America and across the Atlantic ocean, and another descended through the middle of China and across New Holland, and he inferred that these lines communicated near both poles of the earth.

884. **Variation chart.—Isogonal lines.**—In fig. 519 is seen a projection of the lines of equal and no declination, on a Mercators' chart of the earth, embracing observations down to 1835. The

519



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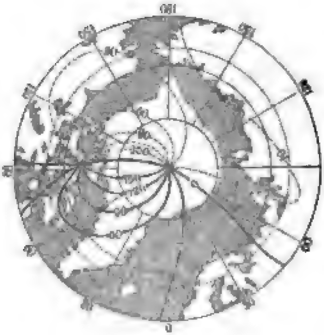
884. Describe the chart, fig. 519. What is shown in fig. 520?

American line of no variation, or *agone*, crosses the eastern point of South America, in latitude 20° S., skirts the windward Antilles, enters North Carolina near cape Look-out, and passing through Staunton, in Virginia., crosses Lake Erie midway on its course to Hudson's Bay. The chief Asiatic agone, (for in fact there are two lines of no variation,) after traversing the Indian Ocean in a southerly direction, crosses the western part of New-Holland near longitude 120° E. All the entire lines on this chart indicate western declination, while the dotted lines mark eastern declination. According to the theory of Gauss, the eminent German astronomer, no lines of equal variation can form diverging branches, or be tangents to each other; but when there is a space within which the declination is less than outside any portion of its limiting line, that line must form a loop, the two branches intersecting at right angles. The observed line of 8° 45′ in the Pacific, beautifully illustrates and confirms this theoretical position, as shown on the chart, fig. 519.

Figure 520 illustrates the circumpolar relations of the corresponding lines of equal variation in the northern hemisphere. It will be seen that much the larger number of the isogonal lines, converge on the mercator's projection at a point near Baffins' Bay, in lat. 73°.0 N., long. 70°.0 W., its opposite pole is to the southward of New Holland.

520



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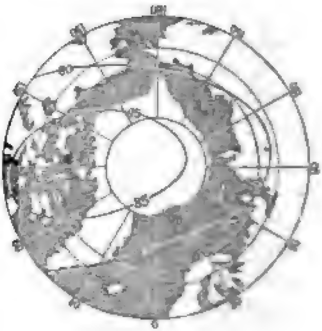

Halley's original chart assumes the existence of two magnetic poles in each hemisphere, one fixed and the other revolving about it in a certain period. Hansteen, in 1828, in his well-known chart, accepts the same view. By Gauss' theory of terrestrial magnetism, only one magnetic pole in each hemisphere is required, and thus far obser-

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Explain the relations of figs. 519 and 520. Where is the North magnetic pole? Where the South?

vation has shown a wonderful conformity between the theory of Gauss and the facts.

885. **Daily variations of the magnetic needle.**—Besides the great secular movements of the magnetic needle already noticed, (883,) it is found to vary sensibly from day to day, and even with the different periods of the same day. The most refined means have been in our time applied to the exact investigation of this phenomenon, first noticed by Graham, a London optician, in 1722. It has been shown that the north pole of the needle begins between seven and eight A. M. to move westward, and this movement continues until one P. M., when it becomes stationary. Soon after one o'clock it slowly returns eastward, and at about ten P. M., the needle again becomes stationary at the point from which it started. During the night, a small oscillation occurs, the north pole moving west until three A. M., and returning again as before. The mean daily change, as observed by Capt. Beaufoy, is not quite one degree. This daily disturbance of the magnetic needle is undoubtedly due to the action of the sun, and it will therefore vary in different latitudes. In the Southern hemisphere, the daily oscillations are of course reversed in direction to those of the northern hemisphere.

The annual variation of the needle was discovered by Cassini, in 1786. We have, therefore, 1st, the great *secular variations*, continued through long periods of time; 2d, *annual variations*, conforming to the movement of the sun in the solstices; 3d, *daily variations*, conforming nearly to the periods of maximum and minimum temperature in each day, and lastly, *irregular variations*, connected with the aurora borealis, or other cosmical phenomena, which Humboldt has called *magnetic storms*.

886. **Dip or inclination.**—A needle, hung as in fig. 522, within a stirrup upon the points *a b*, the whole system being suspended by a thread, will, before magnetizing, if carefully adjusted, stand in any position in which it may be placed. If now the needle be magnetized, it forthwith assumes the position seen in the figure, its pole dipping toward the North pole of the earth. In this latitude, (41° 18′) the dip was, in 1848, 73° 31′·9. Such a needle is called a *dipping needle*, and if constructed as in the figure, it shows both the declination and dip, or inclination, of

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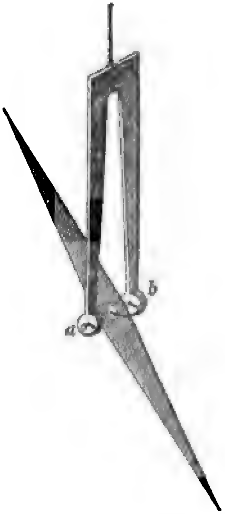
885. Describe the daily variations of the needle. What classes of variation are distinguished? 886. Describe the apparatus, fig 522. How does it stand in this latitude? What is it called?

terrestrial magnetism for any given locality. As the whole system is free to move, it will obviously arrange itself in the magnetic meridian, and its position of equilibrium will be the resultant of the two forces of declination and dip. Approaching the equator, the dipping needle becomes constantly less and less inclined, until at last a point is found where it is quite horizontal, and this point will be in the *magnetic equator;* an imaginary plane near, but not coincident with, the equator of the earth.

522

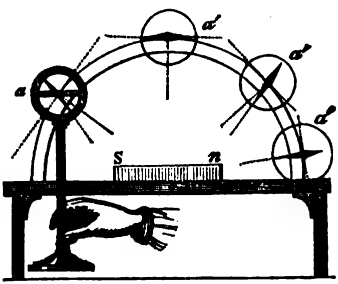


The discovery of the magnetic dip or inclination, was made in 1576, by Robert Norman, a practical optician of London, who constructed the first dipping needle, by which he determined the dip at London at that time to be nearly 72°. The magnetic dip, like the declination, is subject to continual and progressive changes, both secular and periodical, and it is at this moment rapidly decreasing. Thus at London in 1576 it was 71° 50′, in 1676 it had become 73° 30′, and in 1723 it was 74° 42′, having then reached its maximum. In 1790 it had decreased to 71° 3′, and in 1800 to 70° 35′. Sabine, in 1821, fixed it at at 70° 3′, and Kater, in 1830, at 69° 38′. It is now, in England, about 68° 30′, having decreased in 128 years about 6° 12′, or at the rate of nearly 3′ yearly, the mean annual movement from 1830 to 1850 being at the rate of more than 4′ yearly, while between 1723 and 1790 it was about 2·5′ yearly, showing an accelerated and retarded movement in the secular changes of the dipping needle, or magnetic inclination.

887. **The action of the earth's magnetism** on the dipping needle is neatly illustrated by the simple arrangement seen in fig. 523, where the magnetic bar *s n*, is placed horizontally on the diameter of a semi-circle, representing an arc of the meridian, on which a small dipping needle is made to occupy successively the position seen at *a*, *a′*, *a″*, *a‴*.

What two forces influence it? Give the history of this discovery and the changes at London. 887. Describe the experiment shown in fig. 523.

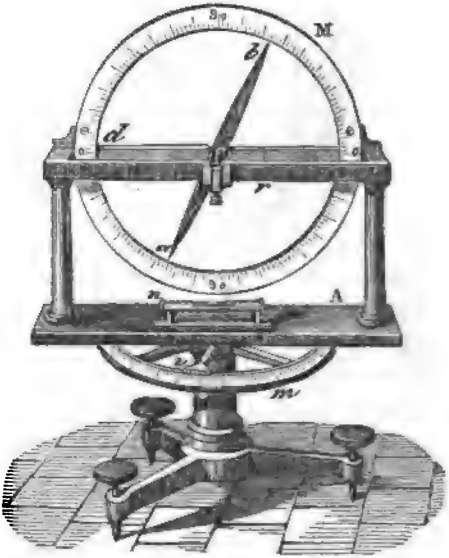
523



At *a'*, the needle is horizontal, being at the magnetic equator, and equally acted on by both poles. In every other position, the influence of one pole must predominate, to a greater or less extent, over the other. Several sewing needles, suspended over a magnetic bar at equal distances, one over each end, one over the centre, and one intermediate, will illustrate the same point satisfactorily.

888. **Dipping needle.**—The dipping needle of Biot, shown in fig. 524, is wholly of brass, and embraces two graduated circles, *m* and *M*, one horizontal and one vertical. The circle, *M*, with its supporting frame, *A*, moves in azimuth over *m*, by which it is placed in the magnetic meridian. It is levelled by the level, *n*, adjusted by three knearled heads in the feet. The needle, *a b*, is suspended on the bars, *r*. To fix the magnetic meridian by this instrument, the circle, *m*, is revolved until the needle, *a b*, stands vertical and points to 90°, it is then in the magnetic equator, a position of course exactly 90° from the magnetic meridian, which is then obtained by revolving the frame, *A*, 90° backwards. The angle,

524



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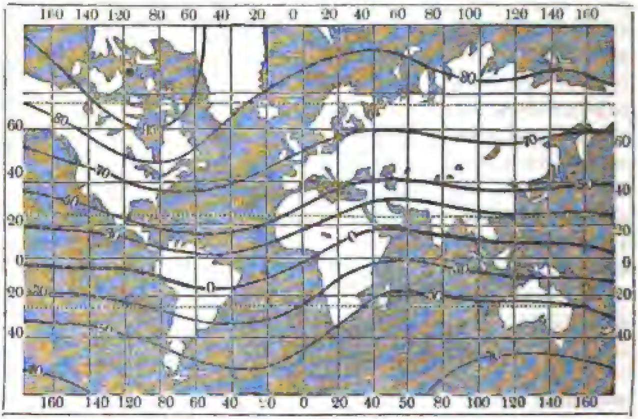
888. Describe Biot's dipping-needle. How is the true magnetic meridian ascertained by it? What errors are involved, and how are they corrected?

a c d, is the angle of inclination, (or dip,) and is read on the arc *M*. Two small errors of observation exist in this instrument; 1st, from the fact that the magnetic axis of the needle does not coincide with the axis of its form, and 2d, from the circumstance that the centre of gravity of the needle does not lie in the points of suspension, and that therefore the angle, *d c a*, is greater or less than the true angle of inclination, by a very small quantity. The first is corrected by reversing the plane of the instrument, by a revolution of 180°, and taking the mean of the two readings; the second, by reversing the polarity of the needle by touch on the opposite poles of two bar magnets, provided for the purpose. By this means, the centre of gravity is brought, first above, and then below the point of suspension, and the mean of the two readings is the true angle sought.

889. **Inclination map, or isoclinal lines.**—In fig. 525, is presented a mercator's projection of the line of no dip, or magnetic equator, and the position of the isoclinal lines of 30°, 50°, 70°, 80°, and 85° north, and 30°, 50°, and 70° south. It will be noticed that the magnetic is below the terrestrial equator, in all the western hemisphere, and is above it in the eastern, crossing it near the island of St. Thomas, in longitude 3 E., and again in the Pacific ocean. These points of intersection of course vary with the progressive changes of the magnetic dip. The greatest declination of the magnetic equator from the equinoctial line, amounts to about 20° N., near 53° E. longitude, and its greatest southern declination is 13°, in about 40° W. longitude, near the bay of Bahia, on the East coast of South America.

525



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889. Describe the chart, fig. 525. What is shown in fig. 521.

The inclination of the needle at any place is, approximately, twice its magnetic latitude. (Kraft.)

Figure 521, shows the relation of the isoclinal lines of 80°, and 85° in the northern hemisphere, to the lines of latitude, and to the N. magnetic pole, near Baffin's bay. Sir James Ross, in 1832, found the needle to dip near Prince Regent's inlet, lat. 70° N., longitude 96° N., within one minute of 90°.

It is to be observed, that the lines of equal magnetic inclination (isoclinal lines,) are found to approach in position, with very considerable conformity, to the isothermal lines, or lines of equal temperature, thus indicating a close relation between the earth's magnetism and the distribution of the terrestrial heat.

890. **Magnetic intensity.**—It is plain, from the phenomena of the magnetic declination and dip already considered, that the distribution of magnetic force over the earth is unequal, although in general it is most active about the poles, and least so about the equator. The question arises, how may the magnetic intensity at any given point of the earth be determined? This question is answered by the use of the *needle of oscillation.* A large number of facts serve to show, that a freely suspended needle in a state of oscillation, is influenced by the magnetic force of the earth, in a way analogous to that of a common pendulum, oscillating by the influence of gravity; and that hence by means of such a needle, we may determine the ratio of the intensity of terrestrial magnetic force throughout the whole extent of the earth's surface.

This mode of determining the magnetic intensity in different regions of the earth, was first suggested by Graham, in 1775, and was afterwards more fully perfected and employed by Coulomb, Humboldt, Hansteen and Gauss. Humboldt carefully determined the time of a given number of oscillations of a small magnetic needle, first at Paris, and afterward in Peru. At Paris, the needle made two hundred and forty-five oscillations in ten minutes: in Peru, it made only two hundred and eleven in the same time. The relative intensities were therefore as the square of these two numbers, or as 1 : 1·3482, which, assuming the point on the magnetic equator in Peru as unity, will give the magnetic intensity at Paris as 1·3482. This kind of observation has since been extended to nearly every known part of the globe, and full tables have been published, giving the results. Thus the intensity at Rio de Janeiro is 0·887; Cape of Good Hope, 0·945;

To what do the isoclinal lines approach? 890. What is magnetic intensity? How is it ascertained? How does the needle of oscillation act? Give Humboldt's results. What American results are named?

Peru, 1·; Naples, 1·274. Paris, 1·348; Berlin, 1·364; London, 1·369; St. Petersburg, 1·403; Baffin's Bay, 1·707.

The most complete statement of the results of American observations on the magnetic elements, has lately been published by Dr. A. D. Bache, in Silliman's Journal, [2] xxiv, p. 1, where all the earlier observations are collated, with the more extended results of the Coast Survey, with maps.

891. **Isodynamic lines**, or lines of equal power, are such as connect places in which observations show the magnetic intensity to be equal. These lines are not always parallel to the isoclinal lines, although nearly so, and the points of greatest and least intensity, are not exactly identical with the points of greatest and least inclination. Hence the intensity of the magnetic equator may not be everywhere the same. These lines are probably curves of double curvature returning into themselves, implying the existence of two intensity poles, the western, near Hudson's Bay, in lat. 50 N., lon. 90° W; and the eastern or Siberian pole, about 70° N., and lon. 120° E. The two southern poles have been placed, one to the south of New Holland, in lat. 60° S., lon. 140° E.; the other, in the South Pacific, also in lat. 60° S., but lon. 120° W. These four poles are not therefore diametrically opposite to each other.

The terrestrial magnetic force increases toward the south pole, nearly in the ratio of 1 : 3, and as both the maximum and minimum magnetic intensity on the globe are found in the southern hemisphere, it would appear that the ratio of 1 : 3 expresses very nearly the maximum and minimum magnetic force of the whole earth. From the profound inquiries of Gauss, it appears that the absolute terrestrial magnetic force, considering the earth as a magnet, is equal to six magnetic steel bars of a pound weight each, magnetized to saturation, for every cubic yard of surface. Compared with one such bar, the total magnetism of the earth is as 8,864,000,000,000,000,000,000 : 1, a most inconceivable proportion. (Harris.)

892. **The inductive power of the earth's magnetism** is manifested by the polarity developed in any bar of soft iron, or of steel, placed in an erect position, as in fig. 526, or better, in the angle of the dip of the place. The end of the bar toward the earth is always austral, boreal magnetism existing at the upper end, *B*, and a neutral point at the centre, *M*. These facts are demonstrated by the action of a small needle, held in the hand

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891. What are isodynamic lines? What is said further of these lines? Give the ratio of intensity in the southern hemisphere. What is Gauss' deduction of the total intensity of the earth? 892. How is the earth's magnetism illustrated in fig. 526?

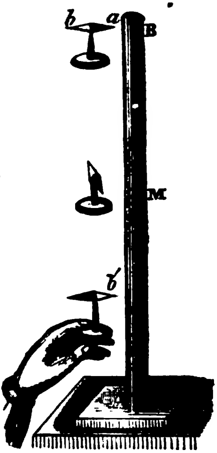
at the three positions, shown in the figure. If the experiment were made in the southern hemisphere, the polarity would be reversed.

For this reason, all masses of iron standing in a vertical position become magnetic. In soft iron this magnetism is transient, but in steel tools, especially such as are subject to vibration, as drills, the magnetism developed is permanent.

Barlow found that globes of iron, like bomb shells, a foot or more in diameter, become miniature copies of the earth by virtue of the inductive force exerted upon them by the earth's magnetism; having a magnetic axis in the line of dip at the place of experiment, and an equator at right angles to their axis. Delicate needles, poised on the equatorial line of such globes, suffered no disturbance, while in any other position on the sphere, both declination and dip were manifest.

Barlow further discovered, that such a sphere of iron, placed in a certain relation to a compass needle on board a ship, united, and harmonized the local attractions of the ship's iron, so as to free the compass from the effects of such disturbing causes.

526



893. **System of simultaneous magnetic observations.**—The distinguished Prussian philosopher, Alex. v. Humboldt, in 1836, proposed to the scientific world to set on foot a series of connected and simultaneous observations, to be made over as large a portion of the earth's surface as possible, for the purpose of eliminating the laws relating to the magnetic forces.

In accordance with this suggestion, the leading governments of Europe, (France excepted,) and many of the scientific societies both in the old and new world, commenced such observations, with instruments specially contrived for the purpose, and in buildings made without iron, both on and beneath the earth's surface. Expeditions were sent to the Arctic and Antarctic circles, to Africa, to South and North America, and to the Pacific ocean, while at numerous stations in India, Russia, Europe, and North and South America, hourly and simultaneous observations have been carried on for a long period, and in many places are still continued. In this way a great mass of facts has been accumulated, from a careful comparison of which the laws

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What was Barlow's observation on shells of iron? 893. Describe the system of magnetic observations. What remarkable result of these is mentioned?

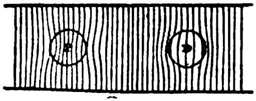
of terrestrial magnetism already announced have been deduced or confirmed.

Perhaps the most remarkable result of these observations is the fact first established by them, that not only the greater variations in the earth's magnetism, but the most minute and irregular disturbances occur at the same instant in places the most distant from each other, showing a wonderful connection and coincidence in the causes of these phenomena throughout the world.

894. **Lines of magnetic force.**—The illustrious English philosopher, Faraday, has demonstrated that all matter is subject to magnetic influence.

As the evidence on which this important induction rests is chiefly derived from the use of electro-magnetism, its particular consideration is more conveniently referred to that subject. His general views, connected with terrestrial magnetism, may be thus stated. All space both above and within the limits of our atmosphere may be regarded as traversed *by lines of force*, among which are the lines of magnetic force. The condition of the space surrounding a magnet, or between its poles, (872,) may be taken as an illustration of this assumption. It is not more difficult to conceive of force existing without matter, than the converse, and it is certain that we know matter chiefly by the effects it produces on certain forces in nature. The lines of magnetic force are assumed to traverse void space without change, but when they come in contact with matter of any kind, they are either concentrated upon it, or dispersed, according to the nature of the matter. Thus we know that a suspended needle is attracted *axially* by a magnet, while a bar of bismuth, and many other solid, liquid, or gaseous bodies, similarly placed between the poles of a magnet, are held in a place at right angles to the axis, or *equatorially*. Hence all substances may be classified either as those which, like iron, point axially, and are called PARAMAGNETIC substances, and those which point equatorially, and termed DIAMAGNETIC. The force which urges bodies to the axial or equatorial lines is not a central force, but a force differing in character in the axial or radial directions. If a liquid paramagnetic body were introduced into the field of force, it would dilate axially, and form a prolate spheroid; while a liquid diamagnetic body would dilate equatorially, and form an oblate spheroid.

527



The diagram, fig. 527, will serve to render more clear the action of diamagnetic and paramagnetic substances, upon the lines of magnetic force. Thus a diamagnetic substance, *D*, expands the lines of

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894. Explain Faraday's lines of magnetic force. Illustrate it from fig. 527. Explain the terms axially and equatorially. What are bodies so attracted called?

force, and causes them to open outwards, while a paramagnetic body, P., concentrates these lines upon itself. Bodies of the first class swing into the equator of force, or lie at right angles to the lines of force, while those of the paramagnetic class become axially arranged, parallel to the lines of force.

895. **Atmospheric magnetism.**—The discovery, by Faraday, of the highly paramagnetic character of oxygen gas, and of the neutral character of nitrogen, the two chief constituents of the atmosphere, is justly esteemed a fact of great importance in studying the phenomena of terrestrial magnetism. We thus see two-ninths of the atmosphere, by weight, consisting of a substance of eminent magnetic capacity, after the manner of iron, and liable to great physical changes of density, temperature, &c., and entirely independent of the solid earth. In this medium hang suspended the magnetic bars, which are used as tests, and this magnetic medium is daily heated and cooled by the sun's rays, and its power of transmitting the lines of magnetic force is thus affected, influencing, undoubtedly, those diurnal changes already considered.

896. **Notions of the origin of the earth's magnetism.**—Two hypotheses have hitherto divided the opinions of philosophers in explaining the phenomena of terrestrial magnetism.

The older of these views, (Hansteen's,) assumes the existence of an independent magnetism in the earth, with its focus, or seat, near the earth's centre. This internal power manifests itself chiefly at four points near the surface, two of which, at the opposite ends of the supposed magnetic axis, are the most energetic, and are known as the magnetic poles. The minor poles have their own independent axis, and move around the principal axis from west to east in the western hemisphere, and the reverse in the southern, giving origin to the well known phenomena of the secular variation of the needle. However well this hypothesis met the facts of terrestrial magnetism some years since, the rapid progress of our knowledge of magnetic phenomena, both terrestrial and general, within a short period has materially changed scientific opinion. The diurnal and irregular variations in the magnetic forces, cannot be explained upon Hansteen's hypothesis, and especially the simultaneous occurrence of these disturbances at different points of observation. Nearly all

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895. What is said of atmospheric magnetism? How is it related to terrestrial magnetism? Illustrate. 896. Give Hansteen's theory of terrestrial magnetism. What objections now exist to this? What is the present opinion?

bodies are now known to be susceptible to magnetic influence, while the maximum and minimum magnetic intensity are found in those regions of the globe where the minimum and maximum of superficial heat exist.

It is hence now argued, that the crust, or surface, and not the interior of the earth, is the seat of the magnetic force. That this force is manifested with least energy at the equator of magnetism, and with increasing power toward the poles, where, as in an artificial magnet, it attains its maximum development, because there we find the most perfect separation of the magnetic fluids: that the coercive force (881) of the materials of the earth's surface is resolved by the solar heat, and that the depth to which this separation occurs is closely connected with the mean heat of the earth's crust, if not absolutely dependent upon it. Axes and poles have, therefore, in view of this hypothesis, no existence in fact, but are merely convenient mathematical terms for expressing our ideas of magnetic phenomena more closely, just as in crystallography we employ the same terms for the same reasons.

In conformity to this view, the manifestation of the magnetic forces will vary with all the diurnal changes of temperature, giving the relation of cause and effect between these changes, and the magnetic perturbations. The annual fluctuations in the mean temperature of the earth's surface, will therefore be reproduced in corresponding movements in magnetic declination and dip. Hence the magnetic meridian, ano the system of isoclinal and isogonic curves ought to correspond closely, ds they do, with isothermal lines, and the peculiar distribution of temperature in both hemispheres. Indeed, we may assume, should this hypothesis prevail, that the differences now noticed between the isothermes and isogones, (due probably to imperfect observations,) will vanish under new and more extended researches.

PRODUCTION OF MAGNETS.

897. **Artificial magnets** are produced (1) by touch, or friction from another magnet, (2,) by induction, (3,) by electrical currents, and (4) by the solar rays.

The method by touch is accomplished by very various modes of manipulation, of which we shall describe only one or two, referring the reader to larger treatises on magnetism for fuller de-

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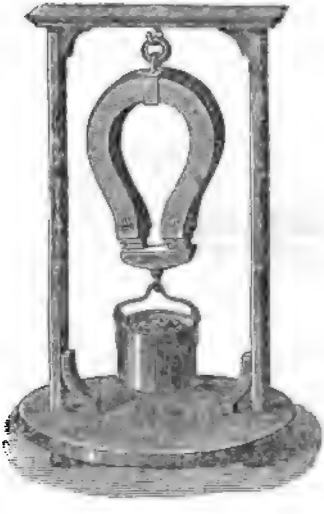
How is terrestrial magnetism related to heat and cold? How is the coercive force of the earth resolved? What of axes and poles in this view? State the conclusions arrived at from this view? 897. How are artificial magnets produced?

tails. Since the introduction of the method by electro-magnetism, the old methods of producing magnets by touch are far less important than formerly.

898. **The circumstances affecting the value of magnets** are chiefly the nature and hardness of the steel, the form and proportion of its parts, and the mode of keeping. The most uniform and fine-grained cast-steel, wrought with as little disturbance of its particles as possible, forms the best magnets.

528



This is tempered as high as possible, and the temper is then drawn by heat to a violet straw color, at which hardness it has been found to receive and retain a maximum of magnetism. The proportions of a bar magnet should be, for width, about one-twentieth the length, and the thickness, one-third to one-fourth the width. In a horse shoe, the distance between the poles ought not to be greater than the width of one of the poles. The faces should be smooth and level, and the whole surface be highly polished. It is quite essential for preserving the power of a magnet, that its poles should be joined by a keeper or armature of soft iron, made to fit its level ends, and be suspended, as seen in fig. 528. Thus armed, a magnet gains power; but if left unarmed, it suffers material loss. Bar magnets are arranged as in fig. 529, either four magnets with their opposite poles in contact, or two magnetic bars, side by side, with two pieces of soft iron joining their opposite poles.

529

899. **Magnets by touch.**—Touch one pole of a powerful mag-

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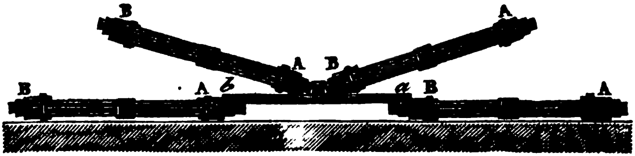
898. What circumstances affect the value of magnets? What temper is best? What proportions of form are given? What is essential to the preservation of this power?

net with one end of a sewing needle, or the point of a pen-knife, and it becomes instantly a magnet, attracting iron-filings and repelling or attracting the magnetic needle. The coercive force has, in this case, been decomposed by simple touch. If the magnet is very powerful, a near approach of the needle to it without contact will develop a feeble magnetism by induction. (902.)

More powerful magnetism is, however, developed by drawing the bar to be magnetized, from its centre to the end, several times over one pole of a magnet, returning it each time through the air, and repeating the stroke in the same direction. Then place the other pole in the middle of the bar, and stroke the opposite end as before.

Two magnets may be placed together, with their dissimilar poles in the middle of the bar, as in fig. 530, and then be moved in opposite directions, at a low angle, to the extremities of the bar, and the impregnation of the bar will be more powerful and speedy if it rests by its ends on the two opposite ends of two other magnets, as practiced by Coulomb. By inspecting the letters in fig. 530, this arrangement will be quite clear. Care is taken to prevent the ends of the two inclined bars from touching, by placing a bit of dry wood between them. This is called *single touch*, and is to be explained in accordance with (880.)

530



To magnetize a bar by means of the *double touch*, two bars or horse shoe magnets are fastened together, with a wedge of dry wood between them, so that their dissimilar poles may be about a quarter of an inch asunder; or a horse shoe magnet may be used if its poles are quite near together. The magnet, in this mode, is placed upright, on the middle of the bar, and is then rapidly drawn towards its end, taking care that neither of its poles glides over the end of the bar. The magnet is then passed over the opposite end of the bar as before. The poles will be dissimilar to those of the touching magnet.

900. **Horse shoe magnets** are easily magnetized by connecting

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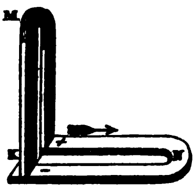
899. Explain magetism by touch. What manipulation is used for single touch? Explain Coulomb's mode, fig. 530. Explain double touch.

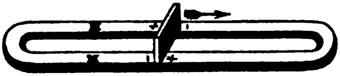
the open ends by a soft iron keeper, while another horse shoe magnet of the same size is passed from the poles to the bend, in the direction of the arrow in fig 531, the poles being arranged, as indicated by the figure.

531



The easiest mode of obtaining a maximum magnetic effect in a bar, by touch, is that of Jacobi, viz.: to rest its ends against the poles of another magnet, and then to draw a piece of soft iron, called a feeder, from it several times along the bar. This mode is applied to horse shoe magnets, as seen in fig. 532. The dissimilar poles are placed together, and the feeder is drawn over the horse shoe, in the direction of the arrow; when it reaches the curve, it is to be replaced, and the process repeated; turn the whole over without separating the poles, and treat the other side in like manner.

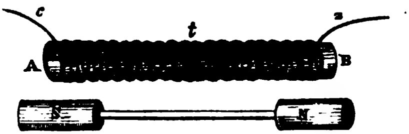
532



A horse shoe of one pound weight may be thus charged, so that it will sustain 26·5 pounds. By the best method of touch before known, fig. 531, 21 lbs. 9 oz. was the highest attainable result. (Peschell.)

901. **Magnets by electro magnetism.**—The mode of producing electro-magnetic currents will be hereafter described. By their means, powerful magnets of soft iron are easily produced, and from these, by the methods of touch just described, very powerful artificial magnets may be made.

533



Logemann, of Haarlem, in Holland, has in this way produced the most powerful magnets ever made. One in possession of the author sustained 28½ lbs.; its own weight being 1 lb. The mode of producing these powerful magnets will be understood from fig. 533. A spiral of insulated copper wire, *t*, is wound on a paste-board tube, *A B*, in the manner of the electro-magnetic helix. The bar to be magnetized is armed with two heavy cores, or cylinders of soft iron, *S N*, just fit-

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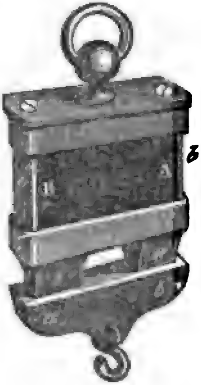
900. How are horse shoe magnets magnetized? Explain the mode in fig. 532. 901. What of magnets by electro-magnetism? What of Logemann's mode? Explain fig. 533.

ting the inside of the spiral; when in its place, the ends of the spiral, *c z*, are connected with a few cells of Grove's or Bunsen's battery, and the powerful temporary magnetism induced in the masses of soft iron, re-acts, to induce an uncommonly strong permanent magnetism in the bar of steel. A horse shoe magnet is charged in a similar way by encircling it with a helix of proper form, with similar armatures of soft iron. The close analogy of this mode to that of Jocobi, in the last section, will be noticed.

902. **Compound magnets** are made of several plates of steel, separately magnetized, as in fig. 507 and 530. As the coercive power of steel appears to be overcome, chiefly, on its surfaces, there is an advantage in multiplying the number of plates, but as each plate serves to neutralize a portion of the polarity of its neighbor, (similar poles, of necessity, being brought into contact,) there is soon found a limit beyond which there is no advantage in extending these batteries.

534



Large magnets are not as powerful, in proportion to their weight, as small ones. Sir Isaac Newton is said to have worn in his finger-ring a magnet, (lode stone,) weighing three grains, and capable of sustaining over 250 times its own weight, (760 grains.) A lode stone of three or four pounds weight, mounted as in fig. 534, can rarely sustain over two or three times its own weight.

The most powerful artificial magnet on record, was that made by Dr. G. Knight, of London, and now in possession of the Royal Society. It consisted of two prismatic bundles, each of 240 powerful bar magnets five feet in length, mounted on wheels; between the end plates of this combination, the poles of the most energetic single magnet were reversed or powerfully reinforced.

903. **Magnetism of steel by the sun's rays.**—Although the fact is doubted by some experimenters, the weight of testimony appears to support the conclusion, that the sun's violet rays possess the power of inducing permanent magnetism, when concentrated by a lens, on steel needles.

904. **To deprive a magnet of its power,** it is only necessary to reverse the order adopted to impart magnetism to it, stroking

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902. What are compound magnets? Give illustrations. What is said of Dr. Knight's magnets? 903. What of solar magnetism?

it from the ends to the centre with poles of the same name opposed. In this way the magnetic virtue may be wholly or very nearly destroyed.

The approach of a feeble magnet to a strong one may reverse its polarity. Leaving it without its keeper greatly impairs its power. Suddenly jerking if off the keeper, or striking it with a hammer, in a way to make it vibrate, does the same. Heat accomplishes the total destruction of magnetism, and in short, anything which weakens its coercive power. Conversely, hanging an armed magnet in the position it would assume if free to obey the solicitation of the forces of terrestrial magnetism, is the best position to favor its greatest development. Every magnet which has been charged while its poles are connected by a keeper, possesses more power before the keeper is removed than after. It is indeed over-charged, and the excess may be likened to that residual force which retains the keeper of an electro-magnet in its place after the circuit which excited it is broken. or to the residual charge of a Leyden jar. Every time the keeper of a magnet is moved suddenly, a loss of power is sustained, and hence the keeper should be removed by sliding it gradually off endways, and only when it is required for the performance of an experiment.

STATICAL OR FRICTIONAL ELECTRICITY.

OF ELECTRICAL PHENOMENA AND THEIR GENERAL LAWS.

905. **Definitions.**—Electricity is the etherial or imponderable power which in one or another of its forms affects all our senses. In this respect it is unlike all other etherial influences. It appears, as far as our knowledge goes, to extend throughout nature, and is probably connected inseparably with matter in every form. Bodies in their natural state give no evidence of its presence, but by different means it may be evoked from all. Hence *statical electricity* implies that condition of this subtle ether existing in all bodies in a state of *electrical quiescence*. Statical electricity is the opposite of that state of excitement following friction, chemical action, &c., which is called *dynamic electricity*, or electricity in motion.

Electricity is a term derived from the Greek for amber, which the

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904. How is a magnet deprived of power? What precautions are given? 905. What is electricity? In what does it reside? How is it evoked? Define the terms statical and dynamic.

ancients knew to be capable of what we now call electrical excitement, when it was rubbed.

906. **The chief sources of electrical excitement are**:—1st, *friction* of dry substances, as of glass, by cats' fur or silk, and of sulphur or resin by flannel: this is ordinary or statical electricity; that of the atmosphere and of common electrical machines. 2d, chemical action, or the contact of dissimilar substances, under circumstances favorable to chemical change. 3d, magnetism, producing magneto electricity. 4th, *heat*, or thermo electricity.

The electricity from all these several modes of excitement differs in degree and intensity, according to its source, but not in kind, and each may, in turn, be cause or effect. Each will be the subject of separate consideration.

907. **Electrical effects.**—A dry and warm glass rod, rubbed with a cats' fur or silk handkerchief, is excited in such a manner as to attract to itself bits of paper, shreds of silk or cotton, metallic leaf, pith, feathers, and a variety of light substances, holding them for an instant, and then repelling them again, to the table or support, as in fig. 535.

In the dark, a feeble bluish light is seen in the path of the rubber. If the excited glass is presented to the knuckle, or to a metallic body, a bright purple spark will dart off from the glass, with crackling sound, to the object presented. Brought near to the face, a creeping sensation is felt, as if a delicate cob-web was in contact with the skin. These effects are produced by the rubber, as well as by the body rubbed, and may be evolved from a number of substances as well as from glass. A peculiar odor always accompanies electrical excitement, thus completing the list of the effects of this subtile agent on our senses, if we add the taste from voltaic electricity.

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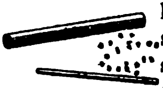

Bodies thus excited are said to be *electrified*; a condition which is only transient.

These very simple experiments, which can be repeated anywhere and with the simplest means, contain the germ of electrical science.

908. **Attraction and repulsion.**—In the electrical pendulum, fig. 536, the pith ball is first attracted to the excited glass or

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906. What are the chief sources of electrical excitement? 907 Enumerate the effects of electrical excitement in the order given.

resin, and at the next instant is repelled, until, by touching some body in connection with the earth, or in some other way, it has parted with its excitement. The two balls in fig. 537, when thus excited, mutually repel each other, because they are similarly excited. The light bodies in fig. 535, oscillate between the table and the rod, first by attraction, and then by repulsion; when, losing their excitement by contact with the table, they are again attracted, and so on. So with the balls in fig. 537. We recognize in these simple experiments the similarity between these actions and the law of magnetic attractions and repulsions. *Bodies similarly excited repel each other; those which are unlike attract.*

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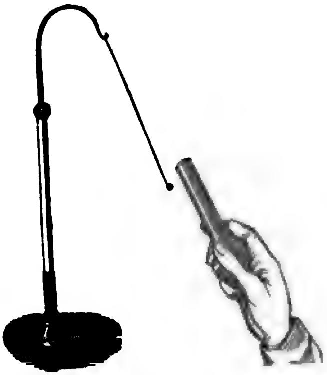

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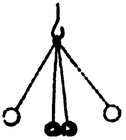

The phenomena of attraction and repulsion are not however so simple as might at first appear, since for their correct explanation a knowledge of the phenomena of *induction* is required, and these remain to be explained further on.

909. **Vitreous and resinous, or positive and negative electricities.**—The species of electrical excitement depends upon the kind of material which is subjected to friction. If the pith balls, fig. 537, are repelled by the excitement from glass rubbed by silk, they will be attracted by a stick of wax, gum lac, or sulphur rubbed by flannel; or *vice versa.*

This difference of action is due to an inherent difference in the two substances, and the kind of electrical excitement which the two respectively produce, is entirely opposite and antagonistic each to the other. The one is *vitreous* or positive, the other *resinous* or negative. This fundamental distinction in the kind of excitement produced by friction in various substances, was first recognized by the

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908. What is the action of the electric pendulum? How do the balls act in fig. 537? What is the law of electrical excitement? What renders these facts less plain than they might at first seem? 909. What is meant by vitreous and resinous? To what are those terms equivalent? What causes this difference?

French philosopher, Du Fay, in 1733, and was re-discovered by Franklin in 1747. Glass and resin are but types of two large classes of substances, which possess more or less perfectly this characteristic difference in respect to the sort of electricity which they are capable of developing.

Electroscopes serve to distinguish the two sorts of electrical excitement from each other. The pith balls, fig. 537, form a convenient electroscope—two silk ribbons, or the electrical pendulum, fig. 536, answer the same purpose. Much more delicate instruments of this kind will be described shortly.

It is only requisite to excite the balls fig. 537, with known vitreous or resinous electricity, when the approach of any excited body whose electrical state is unknown, will, if of the same kind, cause a farther repulsion, and if of a different sort, will occasion an attraction of the balls.

910. **Conductors of electricity.**—Bodies electrically excited part with their excitement variously, some instantly, others very slowly, depending both on the nature of the substance excited, and of those with which it is brought in contact. The pith balls of the electroscope lose their excitement very slowly, the electricity being removed only by the surrounding air. Touched by the finger or a metallic body in connexion with the earth, they are instantly discharged, and return to their natural unexcited condition. The electricity is removed by *conduction* over the touching body. And as bodies vary very much in their power to conduct electricity, they are called *good* and *bad conductors*, or *conductors* and *non-conductors.*

Good conductors propagate the excitement to all parts of their surface, and when in connexion with the earth, part with it as quickly as they receive it.

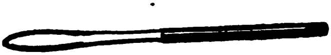
The following are among the good conducting bodies, placed in the order of their conducting power. The metals as a class, (silver and copper standing first, and lead and quicksilver last,) well burnt charcoal, plumbago, coke, hard anthracite, acids, saline solutions, numerous fluids, metallic ores, sea, spring and rain water, ice above 13° F., snow, living things, flame, smoke, vacuum, vapor of alcohol and ether, earths, and moist rocks, powdered glass, and flowers of sulphur.

Who discovered these facts? What are electroscopes? 910. How do bodies part with electricity? How is it with the balls of the electroscope? What is conduction? How are bodies classified with reference thereto?

Bad conductors receive and part with electricity very slowly. If touched by an electrified body, they receive excitement only at the point touched, or if when excited over their whole surface they are touched by a good conductor, the excitement is removed only from the part touched. They retain free electricity for a long time and obstruct its motion.

Good conductors are capable of manifesting electrical excitement only when their communication with the earth is cut off by some bad conductor. So situated, they are said to be *insulated*, and the poor conductors used for this purpose, (glass, resin, or dry wood,) are called *insulators*. Fig. 538, shows a brass tube thus insulated by a handle of glass. Among the chief insulating bodies are the following, placed in the reverse order of their insulating power, viz: dry metallic oxyds, oils, ashes, ice below 13° F., many crystalline bodies, lime and chalk, lycopodium, native caoutchouc, comphor, porcelain, dry vegetables, baked wood, dry air and gases, steam above 212°, leather, parchment, paper, hair, dyed silk, white silk, diamond and precious stones, mica, glass, jet, wax, sulphur, the resins, amber, gum lac. Gutta percha, and whalebone rubber, are among the best insulators known; probably better than gum lac.

538



Some bodies which, when solid, are non-conductors, become so when made liquid by fusion, viz: metallic chlorids, glass, wax, sulphur, resin, &c. Heat diminishes the electric conducting power of metals. Length of conductor retards electrical motion, while an increase in other dimensions favors the rapid transmission of electricity. Every body has a certain *electrical retarding power*, (917,) which is inverse to its conducting power. Tables of electrical conducting powers will be found in larger works; but in general this power is very nearly the same as any given body has for conducting heat.

911. **The earth is the great common reservoir** or receptacle into which all electrical excitements are returned, and regarded as a whole, is a good conductor. The air, even in its ordinary condition, is a very poor conductor, and in view of its immense extent, is by far the most important of non-conductors. It serves to insulate the earth in a non-conducting envelope, more or less perfect, in proportion to its density, and the absence of aqueous va-

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Characterize and enumerate some of the good conductors. Characterize the bad conductors. How may good conductors be excited? What are insulators? Name some of the principal insulators or bad conductors. Which are the most remarkable? How does heat affect some bodies? How fusion?

por. Except for this property of the air, all electrical phenomena would have remained invisible and unknown to us.

In a vacuum, all electrified bodies speedily lose their excitement, while in dry, dense air, they retain it longest. Nevertheless, slight electrical excitement can be produced in a vacuum by friction.

912. **Theories of electricity, or electrical hypotheses.**—Philosophers generally agree in attributing the phenomena of electricity to the existence of an assumed *electrical fluid*. This supposed fluid is so subtle and etherial as to escape detection by all the means used to recognize matter, being imponderable, and manifesting itself only by its effects. It is assumed to pervade all nature, and to exist in a state of combination or electrical quiescence in all bodies in their natural state. This quiescence is disturbed by friction, and various physical and chemical causes. All electrical phenomena are supposed to be due to the efforts of the electrical fluid to regain its previous condition of static equilibrium. Two principal hypotheses have been devised to explain the phenomena of electricity, namely: 1st, that of Franklin and Æpinus; 2d, that of Symmer, sometimes attributed to Du Fay.

913. **Franklin's single-fluid hypothesis** is recommended by its simplicity, and was for a long time the view generally adopted, both in England and America. It assumes a single electrical fluid, whose particles are self-repellant, but attracted by matter of all kinds, combining therewith, and when so combined, losing this self-repellant tendency. This fluid is present in all bodies, but in varying proportion, each substance possessing a certain capacity of saturation peculiar to itself. In its natural state, every substance has exactly its own quantity of the electric fluid, and is consequently in a state of electrical indifference. If any cause of electrical excitement exists, this state of quiescence is disturbed, and the body becomes *negatively* electrical, if its natural charge is diminished, and *positively*, if it is in excess. By this hypothesis, bodies become electrical either by addition to, subtraction from, or disturbance in the equal distribution of, the normal quantity of the electric fluid proper to them. In those bodies which manifest positive electricity, the equilibrium is re-

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911. What is said of the earth? How does the air act in electrical phenomena? 912. To what are electrical phenomena commonly attributed? What are the properties of the supposed fluid? What two hypotheses are named? 913. Explain Franklin's single fluid hypothesis.

stored by parting with the excess, and in those whose excitement is negative, by receiving from surrounding bodies enough to satisfy their deficiency.

This hypothesis will be recognized as strikingly like that commonly received in explanation of the equilibrium of heat.

Æpinus found, that in order to account mathematically for the mutual repulsion of two negatively electrified bodies on the single fluid hypothesis, it was necessary to assume that the particles of matter were mutually repulsive instead of attractive, according to the Newtonian law of universal attraction. This *reductio ad absurdem,* has led to the almost universal rejection of the Franklinian hopothesis.

914. **The hypothesis of Symmer, or Du Fay,** assumes the existence of two fluids, extremely tenuous, imponderable, in the highest degree expansive, mutually repellant, (as a consequence of this expansive nature,) and yet possessing a strong mutual attraction when not opposed by any obstacle. They therefore combine, when favorably situated so to do; and when equally combined, their expansive and repellant forces are neutralized, and electrical quiescence results. Each of these kinds of electricity may exist separately; they are then in a state of antagonism and manifest polarity, and other electrical effects. Every substance becomes thus excited whenever any part of its natural electricity is decomposed by friction or otherwise. If a plate, it may possess the two electricities on its opposite sides, one being vitreous and the other resinous; if a rod, the decomposition of a part of its natural elasticity will make the rod vitreous at one end and resinous at the other. When the cause of excitement ceases, the two fluids reunite, and quiescence is restored. By this hypothesis all electrical phenomena arise from the tendency of the two fluids when separated, to reunite and neutralize each other.

Either view is capable of explaining most electrical phenomena, but the weight of scientific opinion is now in favor of the last. Neither view can be actually true, since the term *fluid* is only a convenient expression for an unknown cause, and there is no reason why we should assume the existence of a separate fluid or ether, each as a medium for light, heat, or magnetic electricity, when it is more in accord-

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What do positive and negative mean in his view? What analogy has this hypothesis? What is the objection discovered by Æpinus? 914. Explain the hypothesis of Symmer. What is said of the two views?

ance with a sound philosophy to assume that these separate manifestations are but functions of the etherial medium which fills the universe, and from whose correlations to the particles of matter, all physical phenomena proceed.

915. **Electrical tension** is a term employed to express that condition of bodies in which the electricity is free—a condition the reverse of electrical quiescence. This condition is well illustrated in the phenomena of the Leyden jar, where there is perfect equilibrium between the excitement of the outer and inner surfaces, due to their antagonism. The energy with which the decomposed electricities reunite, when communication is made between them, shows the state of tension in which they existed. This may be regarded as analogous to the tension of a bent spring, in which equilibrium is regained by a reaction equal to the compressing force. Electrical tension is a condition of constrained equilibrium, and when the free electricities to which it is due, reunite, an *electrical current* is produced from the reaction of the opposing fluids, analogous to mechanical motion from the recoil of a spring. From this state of electrical tension are derived the *primary* effects of electricity, and from electrical currents arise its *secondary* effects. All electrified bodies manifest electrical tension; they attract other bodies, decomposing their natural electricity, deriving from them a portion of the opposite fluid. If this is insufficient to satisfy the antagonism of the excited electric, the attracted bodies are next repelled. (908.) Hence two bodies equally excited, but of opposite names, attract each other, and reunion of the two fluids with electrical indifference results. If one contained an excess of either fluid, both remain excited after contact, with that description of electricity which was in excess; the excess being divided in the ratio of their surfaces.

916. **Electrical currents are either momentary or permanent.** The first occur when contact is formed between substances oppositely excited by friction or otherwise, and their effects are instantaneous and transient.

Permanent electric currents arise only from the sustained action of some continuous cause; as from the continued motion of the electrical machine, or more simply, from the chemical action of

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915. What is electrical tension? What analogies are suggested in explanation of this? How do electric currents arise? What are primary and what secondary electrical effects? 916. What sort of electric currents are named? How are the two produced?

unlike substances, as in the voltaic battery, in which the electrical current is kept up as long as any chemical action exists.

917. **Path and velocity of electric currents.**—If several conducting paths are open to an electric current, it will always choose the shortest, and that in which it meets the least resistance. If the current is powerful, and the conductor inadequately small, its passage will be marked by light, and perhaps by the combustion and deflagration of the conductor. The velocity of static electricity, by Wheatstone's experiments, over a copper wire, was found to be 288,000 miles in a second—nearly half again more than the velocity of light. (838.)

It appears from Dr. Gould's discussion, (Sill: Jour. [2] xi. 161,) of the very numerous telegraphic observations in the U. S., made under the direction of Prof. Bache, for the Coast Survey, and by other astronomers, that the velocity of a voltaic current, when the earth forms part of the circuit, does not exceed 16,000 miles per second, and it has been measured as low as 11,000 miles per second; showing a great retarding force in a conductor of 1500 miles circuit.

LAWS OF ELECTRICAL FORCES AND DISTRIBUTION OF ELECTRICITY UPON THE SURFACE OF BODIES.

918. **Coulomb's laws.**—Coulomb a distinguished French physicist, (died 1806,) by the use of the torsion balance, first demonstrated the following laws of electrical attractions and repulsions.

1st. *Two excited bodies attract and repel each other with a force proportional to the inverse square of their distances from each other.*

2d. *The distances remaining the same, the attractions and repulsions are directly as the quantities of electricity possessed by the two bodies.*

The force of torsion, or resistance of wires to twisting, varies directly with the angle of torsion, inversely as the length of the wire, and directly as the square of its section. Coulomb happily applied these principles, first established by himself, to the measurement of electric forces in his—

919. **Torsion electrometer.**—This instrument, fig. 539, consists of an exterior glass cage, protecting a slender needle, *n o*, of gum lac, suspended by a fine wire of silver or platinum, centrally

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917. What is said of the path of an electric current? What of its velocity? What are the American observations? 918. What are Coulomb's laws? What is the law of torsion?

attached to the under side of the cap, *e*, upon the tube, *d*. This cap is graduated, and turns like the cover of a box. The graduation is read at the vernier, *a*. A small weight, *o*, of brass, keeps the wire tense, while through it the gum lac needle passes. At one end of the needle, *n*, is a small gilded ball of pith, or a disc of tinsel paper. The cover of the glass case is perforated for the free passage of a glass insulating rod, *i*, carrying a polished brass ball at *m*. The glass cage is graduated in a zone at *C*, into 360 degrees, to measure the angular spaces traversed by the needle. The zero of the graduation, and of the arc on the cap, are both made to correspond (by revolving the tube, *d*,) with the normal position of the needle when at rest, and unexcited. The air in the cage is kept dry by a little dry lime, placed in a dish for that purpose, on the bottom, to avoid the loss of electricity.

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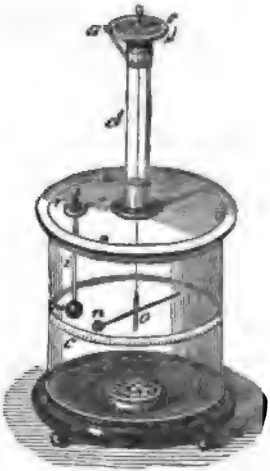

920. **Demonstration of the first law.**—The apparatus being thus arranged, the insulated rod, *i*, is withdrawn, and the ball, *m*, placed in contact with some excited surface—as the electrical machine. Thus excited, *m* is immediately returned to its place by the insulating handle, taking care that it touches nothing. Forthwith the disc, *n*, is attracted to *m*, is oppositely electrified, and then repelled with a force proportioned to the intensity of *m*. After a few oscillations, *n* comes to rest say at 30 degrees on the graduated circle. This angle then represents the repellant force of the electricity on *m*, since the torsion of a wire is directly as the twisting force. But what would be the force requisite to hold the disc, *n*, in equilibrium at half this angular distance, or 15°? Revolving the movable circle, *e*, in the direction of the arrow, we find it is necessary to carry it from 0, to 105°, in order that the needle may point to 15°. The wire is

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919. Describe the torsion electrometer, fig. 589. 920. Explain its use in demonstrating the first law. How is this applied to attractions? Demonstate the second law. What exception has Harris taken to Coulomb's laws?

then twisted at top with a force of 105°, and at bottom with a force of 15°, giving 120° as the angle representing the force with which the two electrified bodies repel each other, at the distance of 15°—or at half the distance we have quadruple the force; at one-third the distance, or 7½°, the force would be 472°·5 + 7·5 = 480°, &c. according to the law of inverse squares.

In like manner, reversing the electricities, we prove that the force with which two electrified bodies attract each other, is inversely proportional to the square of the distance by which they are separated.

921. **Demonstration of the second law.**—Having repelled the needle, *n o*, by the excited ball, *m*, withdraw the latter, and touch it to a second metallic ball of the same size, insulated on a glass handle. The ball, *m*, parts with half its electricity to the second ball. (926.) Now return it to the balance; it will be found that the needle, *n o*, is repelled only half as far as before. Touch *m* again to the second ball, as before, and it will then repel the needle only one-fourth as far as at first, and so on.

Sir Wm. S. Harris, of England, by the use of a bifilar electrometer, which substitutes the force of gravity for that of torsion, has shown that the two laws of Coulomb are not strictly accurate, unless the two excited bodies have the same size and form, or unless the sections of the opposing parts are equal. The result of his determinations is, that the attraction is directly proportional to the number of points immediately opposed to each other, and inversely to the square of their respective distances.

922. **Proof-plane.**—For the purpose of determining the relative quantities of electricity that are found on the different parts of the surface of an electrified conductor, a contrivance called a *proof-plane*, is used. It is nothing but a small disc of tinsel, or metal, insulated, as in the ball, *m*, of the torsion balance, fig. 539. This is touched to the surface whose electricity is to be examined, and receives therefrom a quantity of electricity equal to the sum of both of its own surfaces. It may then be inserted in the balance of torsion, or used on any other electroscope. The electricity on the body touched is diminished to the same extent, but when the proof-plane is small, compared with the area of the excited conductor, no sensible error can arise from this loss. The most important source of error to be guarded against in the use

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922. What is the proof-plane, and how used? What source of error?

of this instrument, arises from the effects of induction, presently to be explained.

928. **Electricity resides only on the outer surfaces** of excited bodies, and not in their substance, or on their interior surfaces. This fact is attributed in part to the repulsive power of the electric fluid acting upon the particles of matter interiorly, thus driving the excitement to the outer surface, where it meets the non-conducting air, and is arrested. It is also due to the inductive influence of the electricity of surrounding bodies, and of the walls of the room. The following experiments will illustrate this law.

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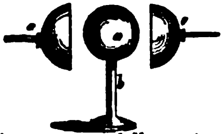
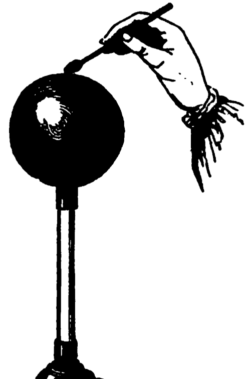


a. Electrify the metal sphere, *a*, fig. 540, on an insulating stand, *b*, and approach to it the two hollow hemispheres of brass, *c c*, insulated, and made accurately to cover the sphere. On removing them, *a* will be found without the least trace of electricity, as may be proved by a delicate electroscope, but the two hemispheres are fully excited. To remove the enveloping hemispheres is to remove the surface of the sphere, and with them its electricity.

541



b. Fig. 541 shows an insulated hollow sphere, with a hole in the top. When this is electrified, the proof-plane may be introduced by the opening, and placed in contact with its inner surface, without acquiring any excitement, (provided care be taken to avoid the inducing effect of the edges of the opening, which may otherwise decompose the neutral electricity of the gum-lac handle,) while from contact with any point of the outside, the proof-plane acquires abundant excitement.

c. Faraday has described a muslin bag in the form of a net, fig. 542, sustained on an insulated ring of wire, and provided at the point of the cone with two insulated silk strings, *c c'*, so that it may be turned inside out at pleasure, without touching it. When this is electrized *exteriorally*, it may be turned inside out by means

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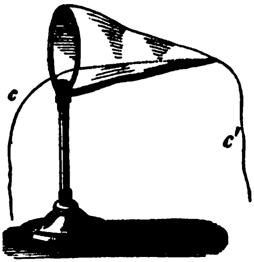
928. Where does the electricity of excited bodies reside? Explain fig. 540. What is shown by fig. 541? What caution is suggested?

of the strings, without a trace of electricity being found on the inside, (which an instant before was the outside,) and this may be repeated several times before the electricity is dissipated. He is in the habit of covering his most delicate electroscopes with muslin bags, to protect them from the influence of excited electrical machines, with entire success.

542



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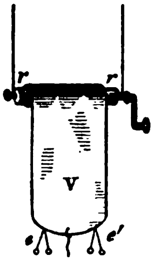
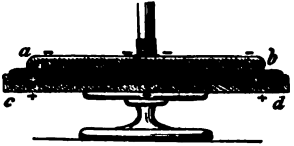


Fig. 543 shows a ribbon of metallic paper wound around a metallic axis, insulated by the silk threads *r r*; two pith balls, *e e'*, are suspended by linen threads, at one end of the ribbon. When the ribbon is wound up, and the whole is electrized, the balls of the electroscopes diverge powerfully. If the ribbon is now unwound by drawing the insulate string below, the electroscope balls gradually fall, and finally come almost in contact: but when the ribbon is again wound up, the balls diverge as before. This may be repeated several times. This beautifully illustrates the relation of surface and intensity. As the surface is increased, the same quantity of electricity is spread out over a larger surface, and its energy declines, but is increased again as the surface is diminished by re-winding the ribbon.

550 p. 585.



c. It appears from these experiments that a ball of wood or pith, covered with tin foil or gold leaf, can accumulate on its surface as much electricity as if it was of solid metal.

It is thus proved that all the electricity with which a conducting body is charged, is disposed on its surface.

924. **Distribution of electricity.**—The form of conductors influences the distribution of electricity on their surface. In a sphere, the distribution is uniform, as would be anticipated from

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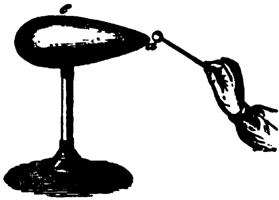
What is Faraday's experiment, fig. 542? How is this law illustrated by fig. 543? What inference is drawn from these experiments? 924. How does form affect the distribution of electricity?

the known properties of the solid. The proof-plane, applied to any part of an excited sphere, acquires, as tested by the balance, the same power. In an elipsoid of revolution, like fig. 544, the proof-plane applied at *a*, gives a much larger angle of torsion in the balance than at any other point, while the minimum is in the vicinity of *e* ; showing a tendency in electrical excitement to accumulate about the extremities of any solid having unequal axes.

544



In cylinders, the concentration of force is within about two inches from each end, and is feeble at the middle. So in plates, the maximum of accumulation is about an inch from the edge. The same is true of the edges and solid angles of prismatic bodies.

925. **The power of points** (first investigated by Franklin) in concentrating electricity is such that the excitement passes off, as rapidly as it accumulates, to the nearest bodies, or is diffused into the ambient air in an electrical brush or pencil, visible in the dark. (940 (6).) This fact follows as a consequence of the tendency of electricity to accumulate at the smaller end of an ellipsoid. The ellipsoid may be so elongated that the electricity escapes—it then becomes a blunt point. These facts are of the greatest importance in the construction of electrical machines.

926. **The loss of electricity in excited bodies**, even when insulated in the best manner, is constant, chiefly from two causes, viz : 1st, the moisture of the air, and 2d, the imperfection of the insulation. The loss from the first cause, in still air of average dryness, is proportioned to the state of electrical tension. Bodies feebly excited, and perfectly well insulated in dry air, retain their state of tension for weeks or months, while those highly excited and not carefully preserved, are soon deprived of all electrical excitement. The rate of loss by imperfect conduction is of course dependent on the non-conducting material used, the perfection of workmanship, and care of the apparatus.

The loss of electricity by an excited conductor, when placed in contact with an unexcited body, insulated from the earth, is in proportion to the relative surfaces of the two bodies. One gains,

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How in the sphere and ellipsoid? How in cylinders? 925. What is the power of points in excited bodies? 926. How do excited bodies lose their electricity?

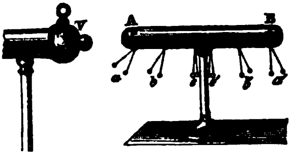
the other loses. Two equal spheres will divide the whole quantity between them. If they remain in contact, the distribution is unequal, being least at the point of contact, and increasing to a maximum at 20° to 30° from the point of contact. The proof-plane determines exactly all such questions.

In a vacuum, a high state of electrical tension is impossible, since the restraining power of the air is wanting. But a feeble tension can be preserved in an exhausted receiver for a long time. The movement of the mercury against the walls of the tube of a barometer, excites electrical tension, and even luminous electricity, as was shown by Cavendish.

INDUCTION OF ELECTRICITY.

927. **Electrical influence or induction.**—Every electrified body is surrounded, so to speak, by an atmosphere of influence, analogous to that surrounding a magnet, (878,) within which every insulated conductor becomes also excited. Bodies so affected are said to be *electrified by induction*, having their neutral electricity decomposed by the tension of the excited conductor, exercised through the intervening air.

545



Let the conductor, *V*, fig. 545, of an electrical machine, be approached within say six inches of an insulated metallic conductor, *A B*. The small electroscopes, *a a'*, suspended beneath its ends, instantly diverge, and at the same time are respectively attracted to *V*, at *A*, and repelled from it at *B*. If *V* is + *A* is — and the remote end, *B*, is plus. The intermediate electroscopes, *d d'*, also diverge, but in a less degree, while those near the middle, *c c'*, do not diverge at all. If, while thus excited, *A B* is withdrawn from *V*, (care being taken not to touch the conducting surface,) the electroscopes will presently cease to indicate any excitement. The explanation of these facts is, that the neutral fluid of *A B*, has been decomposed by the influence of *V*, the + fluid being repelled to *B*, and the — attracted to *A*, while near the centre, (never exactly in the centre,) a neutral point is found, where no decomposition exists. When *V*, the disturbing cause is withdrawn, the two electricities of *A B* unite again, and leave the conductor entirely

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How is it when an excited touches an unexcited insulated body? How is it in a vacuum? 927. What is electrical induction? Explain it from fig. 545. What are the polarities of *A* and *B*? How if *A B* is made in two parts?

passive. If, however, the conductor, *A B*, is made in two parts, joined at the neutral point, and each on a separate glass leg, when it is inductively excited, the two parts may be separated, and each part will then be found, when removed from influence, to possess the same excitement developed in it, under the inductive power of *V*.

By means of a glass tube, or stick of resin gently excited, and approached to one of the electroscopes, it is of course easy to determine the description of excitement in *V*, which we now assume to be +.

928. **The laws of induction may be thus stated.** 1st. A body electrized by induction, possesses no more electricity than before. This is shown by the fact, that as soon as the inducing influence ceases, the two fluids reunite in *A B*, and no trace of excitement remains.

2d. If a conductor, excited by induction, is touched, or made to communicate with the earth in any part of its surface, it parts with a portion of electricity, always of the same name with the inducing body, and it retains the fluid of opposite name. If the inducing cause is then withdrawn, the insulated conductor remains excited, with the fluid of opposite name to that of the inducing body.

Thus we note the important distinctions between a body electrized by induction and by conduction. Induction occasions no transmission of free electricity to the other body; but only a decomposition of the ± electricities of the insulated conductor. Induction produces dissimilar, conduction, similar electricity, to that of the exciting body; and the distance to which electricity of induction extends, greatly exceeds that to which it can be propagated by conduction, where absolute contact or very close proximity is required. A strong analogy exists between electric and magnetic induction. Both magnetism and electricity by *contact*, are of the same name with the body touched. By influence, the neutral fluid of the excited body is decomposed, and the polarities are in accordance with laws already stated.

929. **Induction is an act of contiguous particles.**—Dr. Faraday has modified the usual view of induction just stated, by showing that induction never takes place at a distance, without polarizing the molecules of the intervening non-conductor, causing them to assume a constrained position, which they retain as long as they are under the influence of the inductive body.

Because air and other non-conductors permit the passage of

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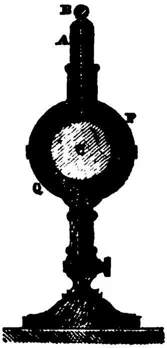
928. What is the first law of electrical induction? What is the second? What distinction is observed between induction and conduction? What analogy with magnetism is noted? 929. How has Faraday modified our notions of electric induction?

electrical influence in this manner, Faraday calls them *dielectrics*, in distinction from *electrics*, or conductors which can become polarized only when insulated by some dielectric. Dielectrics differ in their specific inductive capacity, air being the lowest in the scale, as follows; viz.: air, 1; resin, 1·77; pitch, 1·80; wax, 1·86; glass, 1·90; sulphur, 1·93; shellac, 1·95.

546



The apparatus used by Faraday in determining the relative inductive capacity of air and other gases is seen in fig. 546, consisting, essentially, of two metallic spheres, *C* and *P Q*, of unequal diameter, the smaller placed in the centre of the larger, and insulated from it by a stem of shellac or gutta percha, *A*. The two halves of the outer sphere join in an air-tight joint, like the Magdeburg hemispheres. (319.) The space, *m n*, may be emptied of air by an air-pump, controlled by a cock in the foot, and filled with any other gas or fluid. This apparatus resembles the Leyden jar, (945,) with the advantage of changing the intervening dielectric at pleasure. The balls, *C* and *B*, constitute the charged conductor, upon the surface of which all the electric force is resident by virtue of induction. As the medium in *m n*, may be changed at pleasure, while all other things remain the same, then any changes manifest by the proof-plane and torsion balance, will depend on changes made in the interior. The same end would be reached by having two exactly similar inductive apparatus, with different insulating media. When one was charged and measured, the charge being divided with the other, the ultimate conditions of both indicate by the torsion balance whether or not the media had any specific differences. (For further details, see Faraday's Exp., Res. 1197.)

930. **The attractions and repulsions of light bodies**, (907,) can be explained only in view of the phenomena of induction. The excited tube or resin, decomposes the neutral electricity in the pith balls or bits of paper, repelling the electricity of opposite name, and being thus left of an opposite excitement to the rod or resin, they become attracted to the exciting body, in obedience to electrical law. All cases of electrical repulsion are equally referable to attraction under inductive influence. Thus the apparent repulsion of the two pith balls in an electro-

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What does he call dielectrics and electrics? Describe the apparatus used by Faraday, fig. 546. 930. How are attractions and repulsions explained by induction? Describe the experiment named in this section.

scope, is really the effect of the attraction of surrounding bodies, whose electrical equilibrium is disturbed by the inductive influence of the exciting cause.

The following experiment illustrates, in an interesting manner, the development of electricity, and the attractions and repulsions of light bodies by induction. Support by its edges a pane of dry and warm window-glass, about an inch from the table, on two pieces of dry wood, and place beneath it several pieces of paper or pith balls. Excite the upper surface by friction with a silk handkerchief, the electricity of the glass becomes decomposed, its negative fluid adheres to the silk, and its positive to the upper surface of the glass-plate; this, by induction, acts on the lower surface of the glass, repelling its positive electricity, and attracting its negative, the intervening dialectric being polarized as explained, and the lower surface of the glass electrified by induction through its substance, attracts and repels alternately, the light bodies, like the excited tube. (907.) (Bird.) Numerous experiments illustrative of induction, are given under the electrical machine.

931. **Electrometers.—Cavallo's, Volta's, and Bennett's.**—The electroscopes mentioned in section 908, serve to indicate the presence and name of the electricity. Electrometers are designed to give approximate measures of the quantity of electricity.

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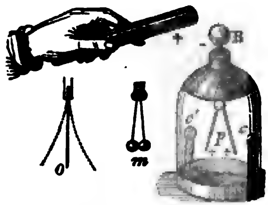

Fig. 547 shows Cavallo's electrometer—a bell jar with a metallic rod and button, *B*, sustaining two pith balls, *m*, at the ends of two wires. Volta substituted for the two pith balls, two delicate blades of straw, *p*. Bennett replaced these by two strips of gold leaf, *o*, placed face to face. When the knob, B, receives electricity, the pith balls, straws, or gold leaves, diverge, and by the degree of their divergence, measured on a graduated arc, the intensity of the electricity is judged of. Two strips of tin foil, *c c'*, are pasted to the inside of the glass bell, to discharge the diverging leaves, when they are repelled, so as touch the sides. Otherwise the inside of the glass jar would be electrified by induction, and render the apparatus useless; and to avoid dampness, the top of the bell is varnished, and the air within, dried by quick lime. Approaching an excited body towards *B*, the gold leaves diverge, because the positive

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931. Distinguish electroscopes from electrometers. Describe fig. 547. How is it used?

fluid, if the excitant is positive, is driven into them, while the negative is attracted to *B*. Touching *B* with the finger, the positive fluid passes off to the earth, but on withdrawing the finger, the leaves diverge under the influence of the negative electricity remaining in the apparatus.

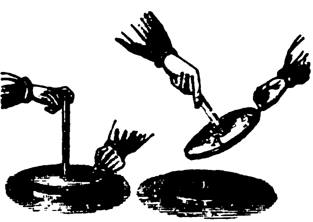
The condensing electrometer is mentioned in section 944 and Bohnenberger's under the dry pile.

ELECTRICAL MACHINES.

932. **The electrophorus.**—Any apparatus by which electrical phenomena may be obtained at pleasure, is an electrical machine. The simplest apparatus of this sort is Volta's *electrophorus*, or carrier of electricity, invented in 1775.

A cake of resin, or a disc of whalebone-india-rubber, or gutta percha, eight or ten inches in diameter, is excited by a fur or warm flannel, and a smaller disc of brass, or tin plate, (with rounded edges,) is placed on it by an insulating handle. Touch the upper surface of the metallic disc with the finger, (fig. 548,) in order to allow the escape to the common reservoir (911) of the negative electricity, resulting from the decomposition of the neutral fluid in the metallic plate by the excited resin. Now removing the finger, raise the disc by the insulating handle, and approach its edge to any conductor, as the knuckle, fig. 549; immediately a strong spark is seen, due to the free positive electricity existing in *A*. Place *A* on *B* again, touch it as before, and the same result may be obtained as often as desired. If *A* is left in repose upon *B*, it will remain charged a long time, even for weeks., and a Leyden jar may be charged with it at any time: or on the table of the laboratory it may be more conveniently used than an ordinary electrical machine, for exploding gases. The section of the electrophorus, seen in fig. 550, p. 579, shows how the inductive action of the excited resin acts, in affecting the electrical nomenclature of each surface, as indicated by the signs + and —

548 549



The phenomena involved in the electrophorus are identical with those explained in (928.) Of course, if the plate, *A*, were

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932. What is an electrical machine? Describe the electrophorus. How is it used? Describe figs. 548, 549 and 550. What are the phenomena of the electrophorus compared with?

raised without touching it, it would manifest no electrical excitement; the two fluids recombining as in the insulated conduct, fig. 544.

933. **The cylinder electrical machine.**—When larger quantities of electricity are required than can be obtained from the means already described, resort is had to machines of larger size, and more power, all of which, however various in form, consist principally of three parts, viz: 1st, a non-conductor, usually of glass, revolving on a horizontal axis, and producing friction; 2d, a *rubber*, against which the non-conductor presses. The rubber is a soft, elastic non-conducting body, as a cushion of leather, usually armed with amalgam, to be described hereafter. 3d, two *conductors*, usually of brass, mounted on glass supports, one to receive the + and the other the — electricity.

In the cylinder machine, fig. 381 *a*, (p. 438,) a smooth cylinder, *M*, of glass, insulated and filled with perfectly dry air, is revolved by the winch before the rubber, *C*, sustained on the insulated prime conductor, *A*, and covering about one-eighth of its surface: an apron of silk, is usually attached to the upper edge of the rubber, and extends as far as the points, *P*, on the second conductor, *B*, designed to receive the + electricity excited at *C*. If the connecting rods, *E D*, are approached as in the figure, and the cylinder is revolved, and there is no connection with the earth, then the + electricity accumulated on the positive conductor, will reunite with a spark with the — electricity of the negative conductor, *A*, again to be decomposed as before at *C*. If the negative conductor, *A*, is connected with the earth by a chain or metallic thread, then, when the machine is worked, a continuous flow of sparks of positive electricity will pass from the positive conductor, *B*, to any conductor near enough to receive them. But if *A* is insulated, and *B* is connected with the earth, then from *E*, a continuous flow of negative electricity is obtained. In this case a flow of positive electricity takes place from the cushion, *C*, through the conductor, *B*, to the earth, thus leaving the conductor *A* charged with negative electricity. This form of cylinder machine was designed by an Englishman named Nairne.

934. **Amalgam.**—No considerable quantity of electricity can be evolved from an electrical machine of glass, unless the rubber is excited with an amalgam composed usually of four parts mercury,

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933. What are the essential parts of an electrical machine? Describe the cylinder machine of Nairne. How is either sort of electricity obtained at pleasure. 934. What is amalgam, and how used?

eight zinc, and two tin, mixed with some unctuous matter and spread on silk or leather. The zinc is first melted; the tin is added, and the mixture stirred, and poured, not too hot, into a wooden box, coated inside with chalk, and into which the heated mercury has been first poured. The lid is put on, and the box violently shaken, until the amalgam becomes cool. It is then finely pulverized in a mortar, and becomes as soft as butter.

935. **Ramsden's plate machine**, as its name indicates, has a plate or plates of glass substituted for the cylinder. This form of apparatus is seen in fig. 548, (frontispiece.) The plate, *F F*, is revolved by the winch, *M*, sustained in a frame, *O O*, of baked wood. Two pair of spring cushions, *a c*, armed with amalgam, produce friction. The conductors, *C C*, collect the electricity from the glass by the points seen on the inside of their curved branches, placed near the surface of the plate. Each of the cushions is connected with the earth by the conductor, *D;* strips of tin foil pasted upon the edges of the frame *O*, and shown in the figure unshaded, communicate between the four sets of cushions and the chain *D*.

This form of apparatus was contrived by Ramsden, of London, in 1776. The earliest electrical machine was made by Otto V. Guerrick, (who invented the air-pump,) and was a globe of sulphur or resin, driven by a motor wheel, the hand being used for friction.

Ramsden's apparatus originally gave only positive electricity. It was so modified by Von Marum as to obviate this defect. In the U. S., our mechanicians have brought all apparatus for electrical illustrations to a degree of perfection leaving little to be desired.

DR. HARE has very ingeniously met the difficulty of obtaining both electricities from the plate machine by making the plate revolve horizontally, and thus allowing the positive and negative conductors to stand like arches in two vertical planes at right angles to each other above the plate. (Sill. Jour. [1] vii, 108.) Dr. Hare was an ardent supporter of the Franklinian hypothesis, and this apparatus was contrived to aid that view.

RITCHIE'S DOUBLE PLATE MACHINE.—The largest electrical machine hitherto constructed, so far as we are advised, is that made for the University of Mississippi, at Oxford, under the direction of President Barnard, by Ritchie, of Boston. The general construction of this

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Describe Ramsden's plate. Who first made an electrical machine? How did Hare construct the machine? Describe Ritchie's machine.

gigantic electrical apparatus may be understood from fig. 551, in which, however, the prime conductors are not shown. These, for greater convenience of manipulation, are made movable on separate supports.

This machine has two plates of French glass, each six feet in diameter, sustained by an insulated steel axle, upon eight cut glass supports, on a frame of rosewood. The plates are excited by four pairs of rubbers, made of brass, and lined with fine wool felt three-eighths of an inch thick, such as is used for the dampers of the grand piano. These are covered with firm India silk, upon which the amalgam is spread. Rubbers of this construction are found to be far more efficient than those in general use. The prime conductors of this machine expose fifty square feet of polished brass cylinders in three sections, about one foot in diameter by seven in length, sustained also on cut-glass insulating pillars. One turn of this machine fills the apartment with an overpowering odor of ozone. It is so arranged as to afford negative electricity from four rubbers. One battery for this machine contains one hundred and twenty glass bells, arranged in detachments, whose coated surfaces expose about ninety square feet of surface. No detailed description of the performance of this superb machine has yet been made public. It cost over three thousand dollars without its batteries.

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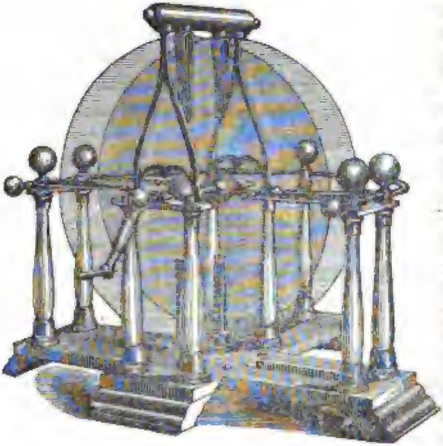

The largest and most famous plate machine mentioned in the books before that of Ritchie, of Boston, both on account of its size and performance, was made by Cuthbertson for Von Marum, in 1755, and was placed in the Tylerian museum, at Haarlem, in Holland. It was a double plate machine, each plate sixty-five inches in diameter, with eight cushions, nearly sixteen inches in length, and twenty-three and a half feet surface in the conductor. It gave three hundred sparks twenty-four inches long in a minute, forked like light-

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935. Describe the great Tylerian machine of Van Marum. What were some of its effects? What glass is best for electrical plates?

ning, and with rays six or eight inches long, branching from the angles of the flash. It deflected a thread six feet long, six inches from a perpendicular, at a distance of thirty-eight feet, and the balls of Cavallo's electroscope (932) diverged half an inch asunder when forty feet distant from it. The prime conductor was supported on three glass pillars sending out collecting branches between the plates. Two men, and sometimes four men, were employed to turn it. When in full force, a single spark from the conductor was able to burn and dissipate a strip of gold leaf twenty inches long and one and a half lines wide. A pointed wire exhibited the appearance of a luminous star when held twenty-eight feet from the conductor.

All glass is not equally fit for electrical plates; that which is white, hard, and free from bubbles, is most esteemed. If too much alkali is used in the composition of the glass, its surface attracts moisture, and soon becomes damp and rough. Such a plate is worthless. The preference given to old plates is due, probably, to the fact, that their composition has enabled them to preserve their properties uninjured.

936. **Care and management of electrical machines.**—Perfect insulation and freedom from dust and roughnesses, are essential to the good condition of all electrical machines. For this end, the glass columns are varnished, to avoid the deposition of moisture, and all the polished surfaces of metal, as well as the glass, must be kept quite clean and free of dust. If the surface of the cylinder or plate becomes streaked with amalgam, it must be wholly removed. It is better not to put any amalgam into immediate contact with the glass, but to spread it upon the cushion pretty thickly, and then to cover it with a piece of silk, a sufficient quantity will pass through the silk,as the machine is worked.

If the glass becomes greasy, it is best washed with rectified camphene, burning fluid, or ether. It is indispensable that the surface of the amalgam should be in good metallic communication with the earth, which is accomplished by the use of tin foil or tinsel. Cushions stuffed with metal filings are preferred by some, chiefly for this reason. A cushion or rubber made of two or three folds of cotton-flannel, between which is laid a continuous strip of tin foil, of the same size with the rubber, works exceedingly well. Pres't Barnard's cushion has already been described. (935.) *Aurum mussivum*, (the bisulphuret of tin,) a yellow bronzy powder, is an excellent substitute for amalgam. It is supposed to suffer chemical decomposition in use, and so to quicken the activity of the machine. Finally, a dry winter air is indispensable for the best working of an electrical

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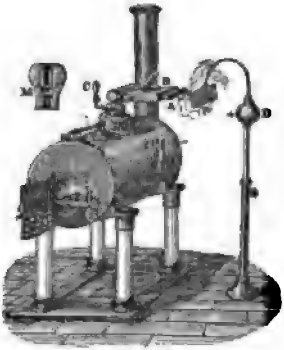
936. What is said of the care and management of electrical machines? How is the glass cleaned? What is said of cushions? What substitute is mentioned for amalgam?

machine; hence radiant heat, falling on the machine or an apartment heated by a dry furnace air, is especially favorable. In carpeted rooms it is desirable to connect the rubber with a gas fixture, to secure a good communication with the common reservoir.

937. **Electricity from steam.**—Armstrong's hydro-electric machine, fig. 552, is designed to illustrate the development of powerful electrical effects from high steam; a fact well known to all concerned in the management of locomotive steam engines, but first scientifically noticed in 1840, by Mr. Armstrong, at New-Castle-on-Tyne. The apparatus, which he contrived to show these effects is a common high pressure steam boiler, about three feet long and twenty inches in diameter, mounted on insulating pillars, and strong enough for a pressure of 200 lbs. to the inch. The steam is suffered to escape by jets, *A*, of a peculiar form, on the side of the box, *B*, into which it is admitted by the cock, *C*. Faraday, in investigating the electricity of steam, found that *dry* steam gave no excitement, and that the electricity resulted from the friction of vesicles of water against the sides of the orifice. Hence, *B* contains a little water, over which the steam escapes, and is partially condensed. The jet has an interrupted passage, seen at *M* to produce friction, and its nozzle is lined with dry box or partridge wood. The vapor escapes against a plate, *P*, covered with metallic points, to collect the electricity, and ending in a brass ball, *D*, insulated from the earth. The boiler is negative, and positive electricity is collected at *D*, provided the water is pure and free from grease. Turpentine and other volatile essences reverse the polarity, while grease or steam from acid, or saline water, destroy all excitement. If the nozzle of the jet ends in ivory or metal, there is also no excitement. A boiler, such as is described, will develop in a given time, as much electricity as four plate machines forty inches in diameter, making sixty turns a minute; a truly surprising result.

552



938. **Other sources of electrical excitement.**—1. The bands

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937. Describe Armstrong's hydroelectric machine? To what does Faraday attribute the excitement? What name has the electricity? What circumstances affect this? What of its power?

of leather, India-rubber or gutta-percha, used to drive machinery, often become powerful sources of resinous electrical excitement, giving sparks, sometimes over twenty inches in length, of negative electricity.

In cotton mills, so much electricity is thus set free, that it becomes necessary to let steam into the carding and roving rooms, to avoid inconvenience from the repulsions and attractions of the cotton. A leathern band, mentioned by Mr. Bachelder, (Am. Jour. Sci. [2] III. 250,) gave sparks to the finger at three feet, and a luminous brush, to a steel point, at seven feet. The discharge from leather, as from all bad conductors, is local, or danger would attend it.

Dr. Franklin, in a letter to Bowdoin, suggested for a portable electrical machine, a cross band of stuffed leather, moved by a winch over drums.

2. The friction of shoe-leather, on woolen carpets, in houses warmed by hot-air furnaces, or steam, in cold weather, is a fertile and curious source of negative electrical excitement.

The young people in the author's house find an unfailing source of amusement in cold weather, in giving electrical shocks, by kisses and otherwise, to unwary people, or in lighting the gas by a spark from the finger or a key handle, after running briskly over the carpet. Prof. Loomis has noticed these effects in the Am. Jour. Sci. [2] x 321, and xxvi, 586, in detail. They appear to be unknown in Europe, owing probably to the fact that European houses are never warmed and dried by hot-air furnaces.

939. **Theory of the electrical machine.**—The phenomena of the electrical machine may be explained, either on the theory of one or of two fluids. The explanations of induction (928) already given, apply equally to the development of free electricity, upon the prime conductors of electrical machines. When the machine is turned, the neutral electricity of the rubber is decomposed, the positive fluid follows the glass, until coming opposite the points on the prime conductor, the negative electricity of the conductor flows out, to unite with the positive of the glass, while the positive fluid of the conductor is repelled to the other end, thus leaving the prime conductor powerfully positive. Reaching the rubber, the neutral fluid of the glass is there decomposed, its negative portion seeks the common reservoir, and the positive follows the revolving glass to the points as before. The conduc-

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938. What other sources of electrical excitement are named? What is said of electrical houses, and the cause? 939. Explain the action of the electrical machine. What becomes of the negative fluid of the prime conductor? How does it become positive? What is said of the action of the amalgam?

tor does not acquire positive electricity from the plate, but gives its negative thereto, thus becoming itself positive.

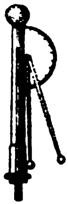
It is still an open question whether the action of the amalgam is chemical or mechanical. (934.) It is certain that an amalgam of silver, or gold, does not act to excite electricity, like amalgams of oxydizable metals, and Dr. Wollaston demonstrated, that the latter did not act in an atmosphere of carbonic acid or nitrogen, free of oxygen.

In all cases, the discharge of an electrical conductor by a spark or otherwise is accompanied by the induction of an opposite excitement in the body receiving the shock, whose opposite electricity, uniting with that of the conductor by a forcible disruption of the intervening dielectric, produces the sound and flash of the electric discharge.

940. **Experimental illustrations of electrical attractions and repulsions.**—A multitude of instructive and amusing experiments may be made with the electrical machine, illustrating the law of attraction. A few must suffice.

1. The Insulating Stool is a bench with glass legs, (a board on four black bottles answers perfectly,) on which a person may stand or sit, while in communication with the electrical machine. Being thus insulated, the free electricity can escape only through the surrounding air—approaching the knuckle to any part of the person or dress of one so situated, a strong spark is received. Except for the hair being repelled, the person charged is not conscious of any change from an ordinary state. A doll's head, with paper hair, set upon one of the conductors, is a common electrical toy.

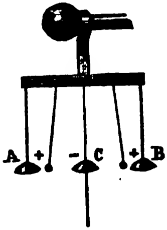
553



2. Henley's Electroscope, fig. 553, serves to mark the degree of tension in the machine by the repulsion of a pith ball at the end of a straw; it is mounted on one of the conductors, and in dry weather remains extended a long time, but in damp weather falls immediately, when the machine stops.

3. Electrical Bells, fig. 554; the bells, *A* and *B*, are suspended by a metallic thread, from the ends of a cross-bar of metal hung on the machine; the bell, *C*, and the two clappers, are hung by insulating threads. *C* is connected with the earth; and when the machine is worked, *A* and *B* become positive, and by induction *C* becomes negative, and the little clappers being alternately attracted and repelled, a constant ringing is kept up as long as the excitement lasts. If the machine is too active, luminous sparks pass, and the bells remain still.

554



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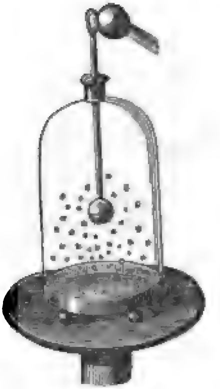
940. Explain the insulating stool and Henley's electroscope. Why do the electrical bells ring?

4. **Volta's Hail-storm** is a contrivance designed to show how (in Volta's view) hail might be produced. A glass bell communicates with the machine, fig. 555, above, and rests on a metal plate in communication with the earth. When the machine is worked, the pith balls on the plate are violently agitated, being drawn up and repelled again actively, while the excitement lasts. A simple bell glass, or large tumbler, electrized by contact of its interior surface with the conductor of an electrical machine, answers quite as well, and may be placed over a heap of pith balls on the table; they are violently thrown about as long as the excitement continues. The dance of puppets is only a substitution of little figures of dancing peasants, made of cork or pith, and placed between two metallic plates.

555



5. **The Electrical Wheel** is composed of several points fixed in a centre, so balanced as to rest on an upright, sustained on one of the conductors, fig. 556; as the machine is worked, the escape of the electricity from the points re-acts on the air with sufficient force to revolve the wheel with activity. The existence of such a current of air, caused by the escape of electricity from points, is further shown—

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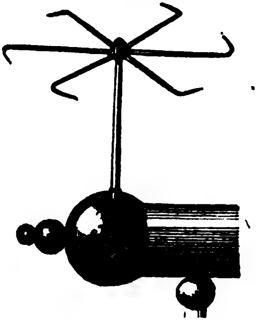

6. **By a Candle flame**; a candle, fig. 557, held before the point, has its flame blown aside by the rush of air accompanying the electricity. If the candle is placed as a conductor, and a point is held out to it, the direction of the flame is altered by the reverse fluid induced on the point, fig. 558.

This experiment has been called *the electrical blow-pipe*. The rush of air from the points may be so energetic from an active machine, as to extinguish the flame. In the dark, all points on an electrical machine emit a stream of light, called the electrical brush. Of course no sparks can be drawn from points, but a Leyden jar may

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What is Volta's hail-storm? Why does the electrical fly revolve? How does a point affect a candle flame? What other illustrations are named?

be silently charged from them. If the point is covered with a ball an inch or two in diameter, its peculiar action ceases, and the ball emits sparks.

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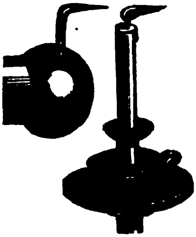

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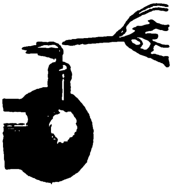

7. Franklin's spider, Ellicot's electrical water pot, the inclined plane, and the electrical planisphere, are other well known forms of apparatus, designed to show the same principle. The catalogues of all leading instrument-makers, contain numerous additional illustrations to the same end.

ACCUMULATED ELECTRICITY AND ITS EFFECTS.

941. **Disguised or latent electricity.**—The phenomena of induction already explained, have a curious and most important extension in the subject of this chapter. When two equal and insulated conductors, equally excited by the two opposite electricities, are separated from each other by only a thin plate of glass, or other dielectric material, no signs whatever of any electrical excitement are communicated by either to an electroscope connected with them. The dilectric prevents the union of the opposing electricities, but not their mutual inductive action, whereby their presence is entirely masked to surrounded bodies.

Removed to some distance from each other, each manifests free electricity, by the divergence of its electroscope. But if they are once more brought together, this evidence of excitement again disappears, and so on, until the imperfect insulation of the air gradually neutralizes all free electricity.

When so situated, the electricities are said to be *latent or disguised*,—paralyzed by their mutual attractions.

942. **The condenser of Æpinus.**—The phenomena of disguised electricity are illustrated by the use of various *condensers*, consisting essentially of two extended metallic surfaces, and an insulating medium. They are sometimes adapted to accumulate electricity of high tension, and sometimes their aid is invoked to render sensible, quantities of electricity, otherwise insensible.

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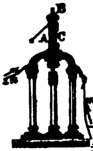
941. What is disguised electricity? 942. What are electrical condensers?

559



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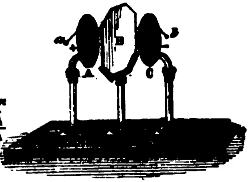

The condenser of Æpinus, fig. 559, 560, is designed for the former purpose. Two polished metallic surfaces, *A C*, with electroscopes, *a*, *b*, and an intermediate thin glass plate, *B*, fig. 560, are all mounted on insulating glass pillars, and slide in a groove cut in the base. In fig. 559, the two discs are placed in close contact with the intervening dielectric, *B*, while by the chain, *n*, positive electricity flows into A, from the excited conductor of an electrical machine.

Did *A* stand alone, it could only receive so much electricity as would raise its surface to the same tension with the prime conductor of the machine. But this condition is wholly changed by the presence of the second plate, *C*, cut off from actual contact with *A* by the dielectric, *B*, but entirely within its inductive influence. A part of the natural fluid of *C* is at once decomposed by this influence of *A*, attracting its negative fluid to the inner surface of *C*, and holding it there, while the corresponding positive fluid from *C* is expelled by the conductor, *m*, to the earth. No free electricity would remain if it were possible for *B* to exist and act as a dielectric without thickness: but as this is evidently impossible, it happens that a little less negative fluid is drawn to the surface of *C*, than exists of positive on *A*, by reason of the thickness of *B*. Consequently the electroscope on *A* remains slightly elevated, (residual charge,) even after some time, while that on *C* continues wholly passive.

But the neutralization of *A*'s positive fluid by the decomposition of an equivalent of natural electricity in *C*, results in lowering the tension of *A*, to the low degree corresponding to its residual free electricity. Hence *A* can receive a fresh charge from the machine, raising its tension to its first condition, and inducing the decomposition of a fresh portion of neutral electricity in *C* as before, and thus the action proceeds, until the whole of the natural fluid of both plates is decomposed and disguised, or rendered latent, excepting that small portion which at each instant constitutes the *free* electricity, equivalent to the difference due to the thickness of *B*, and which, as we have seen, would be null, if *B* could be conceived of as having no thickness. It is this small residue which constitutes the residual charge in the Leyden jar.

In performing this experiment, the knuckle may serve as a con-

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Describe that of Æpinus. What effect have the two plates *A* and *C* on each other? How does *B* affect them? Why does the electroscope *b*, and not *a*, diverge? What determines the point of maximum charge?

ductor to the earth, in place of *m*, when a rapid series of sparks will be received, (positive electricity,) constantly diminishing, and ceasing with the maximum charge of *A* and *C*. This point of maximum charge is dependent on, 1st, the extent of surface in *A B*; 2d, on the tension of the prime conductor; and 3d, on the thickness of *B*.

When the point of saturation in *A* and *B* is reached, and all the electricities possible are disguised in the condenser, the pendulum on *A* still shows only a feeble excitement, although both *A* and *B* are in a state of extreme tension. Withdraw, now, *A* and *C* from *B*, as shown in fig. 560: the electroscopes, *A* and *B*, both show high excitement: restore the plate again as at first, *b* becomes again entirely passive, while *a* shows the same feeble excitement as before. The opposing fluids on *A* and *C* are wholly occupied with their mutual attractions, and only the small excess of + fluid is free, as already explained, to effect the electroscope *B*. The plates *A* and *C* are now fully charged with disguised electricity, rendered latent by mutual inductions, and the polarization of the dialectric *B*. Although apparently passive, they are actually in a state of high tension, as may be proved by their discharge.

943. **The discharge of the condenser** may happen in three ways.—1st, *insensibly*; by the imperfect insulation of the supports, especially if the air is damp; but always gradually.

2d, by the *disruptive discharge*. If the plate, *B*, is too thin in reference to the extent of surface in *A* and *C*, the tension of the opposing fluids will overcome the cohesion of the glass, *B*, and it will be shivered in pieces, with a loud explosion, and brilliant spark. The same spark and explosion may take place without destroying the dielectric, if we use a *discharging rod*, fig. 561, to effect communication between *A* and *C*. If this rod is provided with glass insulating handles, (as in the figure,) the experimenter feels no sensation; but otherwise, or if *A* and *C* are brought into connection by the naked hands, then a powerful *shock* is experienced, convulsing the whole frame. The same sensation, in a feeble degree, is felt when the knuckle receives the sparks of an excited machine.

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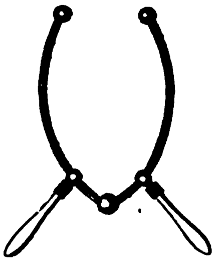


3d, and lastly, the charged plates may be *slowly* discharged by *alternate con-*

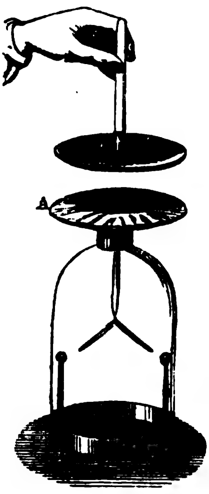
How do *A* and *C* act if separated? How when re-joined? 943. How may the plates be discharged? Describe the disruptive discharge.

nection with the earth. While the condenser is in the condition indicated by fig. 559, touch *C* with the finger; no effect follows; touch *A*, and a feeble spark is received; the electroscope, *a*, falls while, at the same instant, that on *C* is raised to the same degree, showing that what *A* has lost in free positive electricity, *C* has gained in free negative fluid. Touch *C;* a slight shock, a feeble spark, and the fall of the electroscope, *B*, ensue, while the electroscope on *A* again manifests its original excitement. Thus by the alternate discharge of *A* and *C*, the whole of their disguised fluids are gradually set free and discharged.

944. **Volta's condensing electroscope.**—This instrument depends on the principles just explained, and is used to render sensible by condensation, electricity of too feeble a tension to affect the ordinary gold-leaf electrometer. (931.)

The plate *A*, fig. 562, is covered with a waxed silk, slightly larger than the discs; this takes the place of the dielectric, *B*, fig. 560. When the instrument is used, the upper plate is placed in the position shown in fig. 563, and its surface is touched with the body whose excitement we would measure; *e. g.* a crystal of tourmaline. At the same time, the under surface of the lower plate, (in connection with the gold leaves,) is touched by the moistened finger of the other hand. The influence of the excited electric acts in this case exactly as has been already explained in the condenser of Æpinus. No divergence is seen in the gold leaves, until the upper plate of the condenser is raised, as in fig. 562, when the gold leaves promptly diverge: this action being heightened by

562



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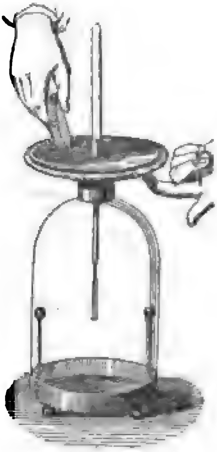
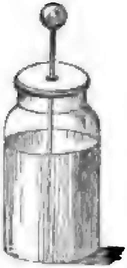


What is its effect on the human frame? How are they slowly discharged? 944. Describe Volta's condensing electrometer.

the inductive influence of two little balls of polished brass, rising within the glass as high as the lower edge of the gold leaves.

945. **The Leyden jar.**—Accident led to the discovery of this remarkable piece of apparatus, long before its principles were made clear by the condenser of Æpinus, and the explanations of Franklin. It consists of a thin glass jar, fig. 564, coated inside and outside with tin foil, as far as the bend of the neck. The inner surface is extended by the wire, carrying a brass knob at top, touching the inner coating by a piece of chain or wire, and sustained in its place by passing through a non-conducting cover.

564



The relations of the jar and the two metallic coatings, will be seen by fig. 565, showing in section a Leyden jar, the parts of which are separable, and its wire bent conveniently into a hook, to suspend it on the machine. It will be seen at a glance that this arrangement is identical in principle with the condenser of Æpinus, and the electrical plates of Franklin. If the knob, *b*, of the Leyden jar, insulated upon a stand, fig. 566, is presented to the conductor, *a*, of the electrical machine in action, only a single spark or so, will enter it, unless a way is provided, as by the conductor, *c*, for the escape of the similar electricity from the exterior coating, while its opposite is then fixed as in *C*, fig. 560. The charging of the jar then proceeds, and for every spark which darts from *a* to *b*, a corresponding one of similar electricity, is seen to escape from the outer coating to *c*. When it is held in the hand, the same effect follows through the arm, accompanied by a slight twinge in the nerves. Presently the point of saturation is reached, the two decomposed electricities are latent, either coating may be fearlessly touched alone, but as soon as by the discharger or otherwise, communication made between them, a loud snap and brilliant spark follow with a violent shock.

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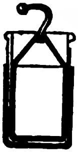

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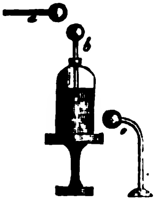

The invention of the Leyden jar, or vial, is commonly attributed to Cunæus or Mushenbroek of Leyden, in 1746. Von Kleist, dean of the chapter at Comin, in Pomerania, also independently discovered this important instrument by a similar accident.

With a view to fix electricity in some insulated substance, Cunæus, in 1746, led electricity into a small vial containing water, by a bent nail thrust through the cork, and hung on the prime conductor. Endeavoring, in one of these trials, to detach the vial and nail

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945. What is said of the Leyden jar? Describe it.

from the electrical machine, Cunæus, to his great amazement, received a violent shock. Von Kleist, in the course of a valuable series of experiments (1745) on electricity, led the fluid by a brass wire or pin into a bottle containing mercury. 'As soon,' he says, 'as this little glass, with the pin, is removed from the electrical machine, a flaming pencil issues from it so long, that I have been able to walk sixty paces in the room with this little burning machine; and if the finger or a piece of money be held againt the electrified pin, the stroke coming out is so strong that both arms and shoulders are shaken thereby.'

This discovery of so wonderful a power in nature, before unsuspected, created immense excitement over the civilized world, and it was precisely at this time that Franklin immortalized himself by his contributions to the new science. He explains the action of the Leyden vial by his single fluid hypothesis, in his 'observations and experiments on electricity,' in a manner which must ever win for him the reputation of a profound philosopher.

946. **Electricity in the Leyden jar resides on the glass.**—In fig. 567, the jar, *A*, is composed of the three separable pieces; *B*, the glass, *C*, its outer, and *D*, its inner metallic coatings. When this jar is charged, and set on an insulating surface, it may be separated into its three parts without being discharged; but *C* and *D* will then be found by the electroscope entirely free from excitement, while *B* remains strongly excited. Putting the parts together again as in *A*, the jar will be found charged as at first, if the air is dry, and too much time has not passed.

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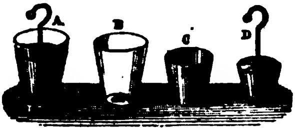

947. **The electric battery.**—As the charge of the Leyden jar is, other things being equal, directly as its surface, large jars are plainly of more power than small ones. But a limit of size is soon reached, which the thickness of glass required for strength, and other circumstances, render it unprofitable to pass. Hence several coated jars, of moderate size, are united by joining all their inner coatings by metallic rods, and all their outer coatings by a common conducting base, as shown in fig. 568. Such an arrangement is called an *electrical battery*. When charged from a common source, and discharged in the usual way, they all act as one great jar, the result being in not quite the ratio of the number of jars, but nearly so. Hence, the smaller the number,

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What is it like? How is it charged—suppose it to be insulated? What of its history? What is said of Franklin's explanation?

the thinner the glass, and greater the size of the jars, the better, and several batteries of seven and nine jars, united to the charging rods of the central jars, are preferable to more extended single series. They are charged by connecting the interior with the prime conductor by *t*, and the exterior with the earth. If the battery is extensive, and the machine powerful, great caution is requisite to avoid receiving its shock; an accident which might be serious in its consequences.

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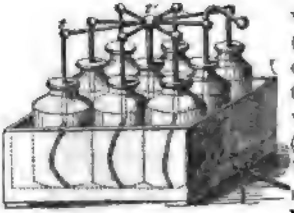

The battery used by Von Marum, with the machine already noticed, (935,) embraced one hundred jars, each thirteen inches in diameter and two feet high The coated surface was five hundred and fifty square feet, (five and a half feet to each jar.) When fully charged, its force was irresistible. A bar of steel nine inches long, half an inch wide, and one-twelfth of an inch thick, was rendered powerfully magnetic by the discharge. A small iron wire, twenty-five feet long, was deflagrated, and various metals were dissipated and raised in vapor, when placed in the circuit of discharge. A book of 200 pages was pierced by it, and blocks of hard wood, four inches square, split in fragments.

948. **Discharge in cascade.**—A series of two or three Leyden jars may be placed horizontally upon insulating stands, so that the interior of each succeeding one may receive the spark from the outer coatings of the one preceding.

This mode of charging cannot be carried beyond two or three jars, owing to the accumulated resistance soon vitiating the result. But Mr. Boggs, of London, has very ingeniously contrived an electric battery, the jars of which are charged together, but are discharged consecutively. Each jar is supported in a horizontal position on a vertical spindle, their knobs, while being charged, pointing outward, like the radii of a circle, and when the battery is to be discharged, the knobs, by a quarter revolution, are brought opposite, each to the bottom of the next jar. In this way the disruptive power or intensity of the spark is multiplied as the jars, the *quantity* remaining the same. Mr. Boggs is said to have discharged his battery of twelve jars through a space of twelve feet. (Sill. Jour: [2] vii, 418.)

949. **The diamond jar.**—To show that the coatings of the jar convey the electricity collected on the glass to the point where it

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94. Where is the electricity of the Leyden jar resident? Illustrate it from fig. 567. 947. What is the electric battery? How constructed and used? Describe Von Marum's and its effects. 948. What is discharge in cascade? What is Boggs' mode?

meets the cause of discharge, a jar may be coated, like fig. 569, with metallic filings, or patches of tin-foil, cut in lozenges, (a diamond jar,) the wire of which is bent over so as to bring the ball near the outer coating, which connects by a chain with the earth. When the machine, (on whose arm this jar is hung,) is worked, a brilliant spark is seen at intervals to dart from the knob to the outer coating, and thence to spread in zigzag courses over the whole surface.

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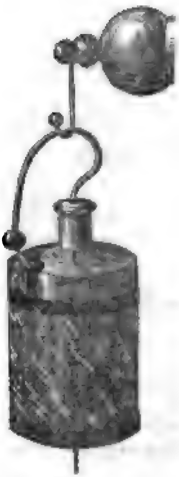

950. **The universal discharger.**—Various contrivances are in use for regulating or measuring the discharge of the electric battery, and the single jar. Of these, Henley's universal discharger, fig. 570, is, perhaps, the most useful. By means of this simple apparatus, the electrical fluid may be made to pass through any substance placed upon the table, *t*. Two rods, sliding in the joints *a a'*, end in balls, *c c'* covering points which can be exposed by their removal. The rod, *a'*, connects with the positive side of the battery, for example, while by the discharging rod, fig. 561, communication can be made at pleasure between *a* and the negative side of the battery, by a chain or metallic thread.

The charge of the battery may be prevented from passing a given limit, by using the discharging electrometers of Lane or Cuthbertson, in which a ball is sustained at such a distance from the discharging knob of the battery, that when its charge reaches the proper tension, it discharges itself.

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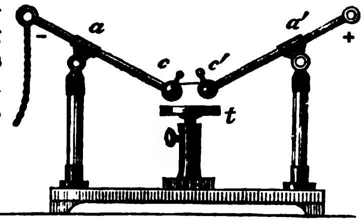

A beautiful illustration of the slow discharge of a charged jar is seen in fig. 571, where a charged Leyden jar, with a small bell in place of the knob, is set upon a board, near to a little brass ball, hung from a silken thread, upon a wire, carrying a second ball in connection with the earth by *A B*. The effect is, that

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949. What does the diamond jar show? 950. Describe Henley's universal discharger. How may the battery charge be limited? How is the slow discharge illustrated?

the + electricity of the jar attracts the little ball, but after striking the bell, the ball is repelled, until, coming in contact with the other bell, it is discharged, and so on for many hours, this little chime is rung by the electrical pendulum.

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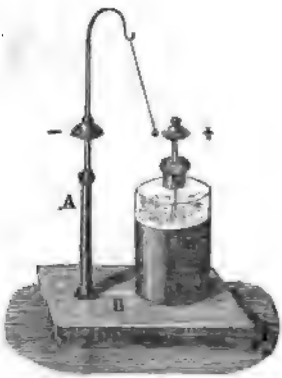

951. **The electric light and spark** result from the re-union of the two electricities. Every electrical discharge produces expansion of the air, and the form and color of the spark are materially influenced by the density and chemical composition of the gaseous medium in which it passes. The character of the sparks depends on the form, area, and electrical intensity of the discharging surfaces, as also on the kind of electricity on the conductor in which the spark originates; from the negative conductor the sparks are far less dense and powerful.

In Kinersley's thermometer, fig. 572, the agitation and expansion of the air following an explosion is clearly seen. A portion of water in the larger vessel, which is air-tight, communicates freely with the small open tube, attached to the foot, and ending in a narrow glass tube. When an electrical discharge takes place through the apparatus, the consequent expansion of the air violently raises the column in the smaller tube, but after the commotion is over, the fluid gradually regains its original level, as the air in the larger vessel cools. *The electrical mortar* discharges its ball by the force of expanded air, at the moment of electrical discharge.

The electrical egg.—In a vacuum, the spark becomes an ovoidal tuft of light, uniting the conductors. The apparatus, fig. 573, is designed to show these effects. A large egg-shaped glass vessel is mounted at the lower extremity with a stop-cock, for attaching it to the air-pump, in order to remove the whole or a part of the air, or to replace it by vapor of alcohol, ether, or any other gas not acting on brass. By the rod, *A*, connection is established with the electrical machine, while the distance between the electrical poles, *B C*, may be adjusted by sliding the upper rod in its air-tight socket. This apparatus is called the electrical or philosophical egg. The

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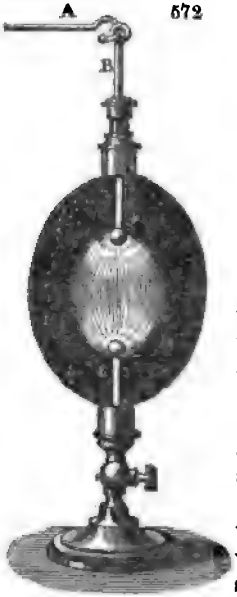
951. What is said of the electric spark? Describe Kincrsley's thermometer. How is the spark in vacuo? Describe the fig. 573.

rarer the air the more globular becomes the spheroid, and at the same time less brilliant. The *auroral tube* is only a modification of the same apparatus.

572



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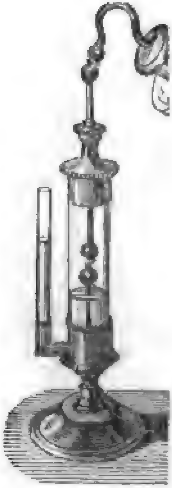
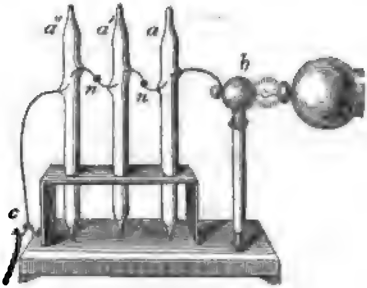


This apparatus is also used with splendid effect with Ruhmkorff's induction coil. (Electro Dynamics.)

952.* **The color of the electrical spark** varies with the nature and density of the gaseous medium through which it passes. Faraday observed that in air, oxygen, and dry chlorohydric acid gas, the spark was white, with a light bluish shade, especially in air. In the heavy thunder-storms common in an American summer, the light of a powerful flash of lightning is distinctly purple, and sometimes violet. In nitrogen it is blue or purple, and gives a remarkable sound; in hydrogen it is crimson, and disappears when the gas is rarefied, in carbonic acid the color is green, and the form of spark very irregular; in oxyd of carbon it is sometimes green and sometimes red; in chlorine it is green.

574



The little apparatus, fig. 574, is well calculated to show these effects by contrast at one view. The three tubes, *a a' a''* are respectively filled with various gases and sealed. Each tube has two short platina wires, *n n*, soldered into its sides, through which the electric spark from *b* must pass on its way to the ground by *c*.

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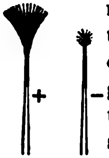
952. What is the color of the spark in different media?

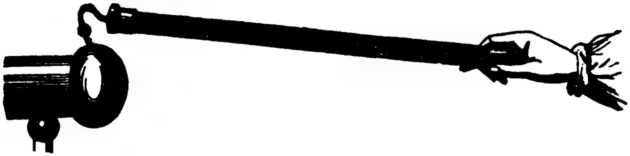
953. Difference between the positive and negative spark.—The tuft of light from positive electricity is far more beautiful than that from negative, as seen from the ends of two points. Thus while positive electricity gives an opening sheaf of light, negative electricity gives only a small star, fig. 575. In rarefied air, these differences are much less apparent. Faraday suggests that they are due, chiefly, to the greater facility with which negative electricity escapes in air, than positive, as conductors, negatively charged, lose their excitement sooner than those positively charged.

575



954. Scintillating tube and magic squares.—Every collection of electrical apparatus contains these familiar pieces of apparatus, illustrative of the phenomena of the electric spark. The scintillating tube, fig. 576, has rows of lozenge-shaped pieces of tin foil pasted on its interior, usually in a spiral, and when held by the hand, as shown in the figure, the electricity flashes from point to point at the same apparent instant, producing a most agreeable effect.

576.



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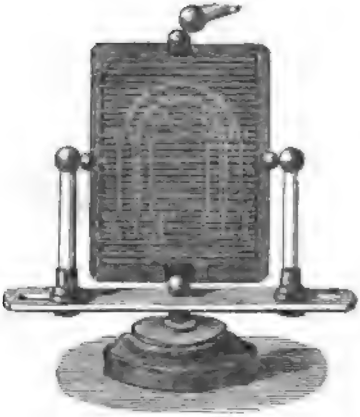

The magic squares are panes of glass on which are interrupted strips of tin foil, cut to represent some design, to be made visible only when a spark passes. These squares are mounted on a foot, in connection with the earth, and are set near the ball of the prime conductor.

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953. What is the difference between the positive and negative spark? To what has this been attributed? 954. What are the scintillating tube and magic squares?

By scattering metallic filings over a varnished surface of glass, the same effect is produced as upon the jar, fig 569.

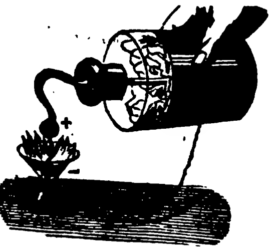
955. **Effects of the electric discharge.**—The effects of the electric discharge are chiefly, 1st, physiological; 2d, physical; 3d, mechanical; 4th, chemical. The passage of the electricities through bodies, is sometimes impeded by their bad conducting power, or by want of proper dimensions; and in either case, a powerful electric discharge manifests itself in one of those modes.

956. **Physiological effects.**—These are seen in the shock experienced by all living beings, in the passage of electricity through any of their members. Any number of persons joined hand to hand, will receive, at the same instant, the shock of an electric battery. Abbe Nollet, imparted it to over six hundred persons in his convent at one time—those in the middle of the chain being little less affected than those near the conductors.

A person charged on the insulating stool, feels a prickly heat and glow of the skin, resulting in perspiration. Many useful applications have been been devised of this agent in medicine, for which, consult Channing's medical electricity. It needs hardly to be said, that the full shock of a powerful battery will destroy life in man. Sparks, fifteen or eighteen inches long, begin to be unsafe, if from large surfaces. Small animals, as birds, are easily killed by a moderate discharge, on the table of the universal discharger. Fig. 970.

957. **Inflammation of combustibles.**—Although no sense of heat is felt when the knuckle receives strong sparks from an active machine, yet the smallest spark serves to inflame ether, whether from a Leyden jar, from the finger, or more stikingly, from an icicle held in the fingers of one mounted on an insulating stool.

578



The ether is placed in a metallic cup, and the spark should be drawn on its edge, moist with ether. Gunpowder placed on the table of the universal discharger, over the *points* of the rods, *a a'*, fig. 970, is simply thrown about, without being fired; but if a wet string, in place of one of the conducting wires, forms part of the connection, its retarding power is such as to fire the powder. The lighting of gas from the finger of one charged by

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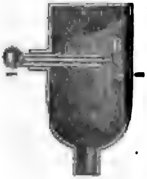
955. Classify the effects of the electrical discharge. 956. What are its physiological effects? 957. What is said of the inflammation of combustibles?

running on a carpet, has already been mentioned, (938, (2).) Lycopodium, alcohol, a newly extinguished candle, and many other combustibles, are also easily inflamed by the spark. A gold leaf confined between two glass plates with the edges hanging out, will burn with the explosion of the glass, and if held between cards, will stain them with purple oxyd of gold. Silhouette likenesses of Franklin are thus printed: a powerful current from a battery is needed for this.

579



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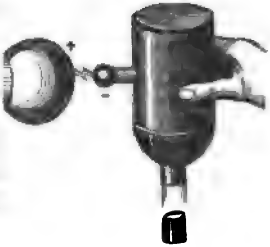
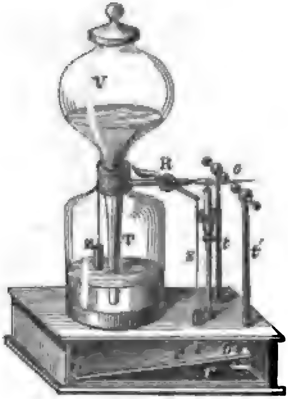


958. **Union of elements effected by electricity.**—A mixture of hydrogen, two volumes, and of oxygen one volume, or of hydrogen, with several times its volume of common air, is exploded by a spark passing through the containing vessel, *e. g.* the tin air-pistol, called 'Volta's pistol,' fig. 579, is provided with an insulated conductor, ending near the inner surface of the pistol at *E*. Its mouth is closed tighly by a cork, and the spark caused to pass by holding it near the prime conductor, fig. 580, or to the electrophorus. The cork is then violently expelled, by the expansion of steam, with a loud explosion.

581



959. **Volta's electrical lamp.**—A self-regulating hydrogen apparatus is seen in fig. 581, similar in its action to that described in (354.) In its base drawer is an electrophorus, *r P*, the plate, *P*, of which is always charged. A silk cord connects the upper plate, *P*, with the gas cock, *R*, in such a way that when the gas in *T* is drawn, the communication is affected at *o*, with the insulated wire *t'*, and the electricity thus finds its way in a spark between the buttons at *O*, and escapes to the earth by *t*. As the hydrogen is flowing at that moment from the jet, it is inflamed, and kindles a little candle

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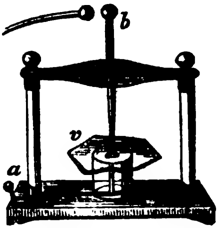
958. How is union of elements effected by electricity? 959. Describe Volta's electrical lamp.

standing in its path. Every time the cock, *R*, is moved, the plate, *P*, rises, and communicates a spark. With care, this instrument remains in action for weeks, from a single excitement.

960. **The mechanical effects of the electrical discharge.**—Any thin non-conducting substance placed between the balls of the universal discharger, is either pierced or broken where the fluid passes. The phenomena attending these experiments are curious and instructive in point of theory.

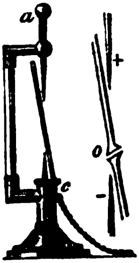
Glass is pierced when a thin piece of glass, *v*, is placed in the position seen in fig. 582, between the points of the conductors, *a b*, a small hole will be made through the glass, as if with a drill, provided the effect of the fluid is concentrated by placing a drop of oil at the point to be pierced. The hole is circular, starred, and its edges smooth, and sometimes it remains filled with the powdered glass in fine dust, easily removed. It requires a powerful battery to pierce glass one-twelfth of an inch thick.

582



If a card is placed in the path of the fluid, it is pierced with a raised edge, (burr,) on both sides of the hole. When the card is placed obliquely, as seen in fig. 583, between the points, *a c*, of the insulating holder, the hole is made in the place and direction seen at *o* in the section; that is, nearer the negative pole, its edges being raised, or thickened, a circumstance due, probably to the decomposition of the neutral fluid in the card, occasioning a rush of electricity in both directions. This has been esteemed a fact inexplicable, on the single fluid hypothesis, while its position, always near to the negative pole, indicates that the negative fluid passes less readily through the air than the positive. Many other examples of the fracture, or dispersion of non-conducting bodies, may be gathered from the larger treatises.

583



961. **The chemical effects** of statical electricity are generally feeble. Besides those before alluded to, (958,) Wollaston, with very fine points of gold wire immersed in water, decomposed water in a very limited manner. A paper moistened with iodid or bromid of potassium, is stained brown by the electrical

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960. What are the mechanical effects of the electrical discharge? Illustrate them from figs. 582 and 583. 961. Describe its chemical effects.

discharge when it is laid upon the scintillating square, (fig. 577.) Olefiant gas, sulphuric acid, chlorohydric acid, ammonia, and nitrous oxyd, are decomposed by the electric discharge, with the separation of their constituent elements, and carbonic acid is decomposed into oxygen, and oxyd of carbon. The elements of the air unite under a prolonged series of sparks, (Pristley,) to form nitric acid, (Cavendish,) and lightning in the atmosphere, forms the same compound, as the analysis of rain-water has shown. (Liebig.) Numerous other evidences of the chemical effects of electricity have been recorded; perhaps the most important of these, is that atmospheric effect called—

962. **Ozone.**—This term is derived from the Greek, in allusion to the peculiar odor which is always perceived after an electrical discharge or excitation of a machine, and sometimes improperly compared to the odor of sulphur, which it does not all resemble. It is due to a remarkable state or condition induced in oxygen gas by electricity, (and by several other causes also.) Mr. Sconbein, of Basle, has devoted himself to the study of the curious properties of this singular product, the record of which belongs rather to chemistry than to physics.

Atmospheric Electricity.

963. **Franklin's kite.**—We owe to Dr. Franklin the demonstration that the phenomena of a thunder-storm are due to electricity, identical with that excited in electrical experiments. He proposed two modes, in 1749, by which he supposed electricity might be drawn from the clouds. Dalibard, at his suggestion, erected in the open air near Paris, in 1752, a pointed iron rod, 40 feet long, and insulated. On the 10th of May, 1752, electrical sparks were obtained from this rod, with the usual snapping sound. In June of the same year, Franklin, tired of waiting for the erection of a tall spire in Philadelphia on which to place his pointed conductor, conceived the idea of reaching the higher regions of the air by a kite. This he formed of a silk handkerchief stretched over two light cedar sticks. It had a pointed wire at top, and a silken cord insulated it from the hempen string, at the lower end of which he tied an iron key.

Watching the approach of a thunder storm he raised the kite, and soon had the satisfaction of seeing the fibres of the hempen

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962. What is ozone? 963. What was Franklin's experiment of the kite? Give the dates and history. What is said further of Romas and Richmann?

string bristle and repel each other, and finally when the rain had rendered the string sufficiently a conductor, he enjoyed the unspeakable satisfaction of seeing long electrical sparks dart from the iron key. Thus was realized by actual experiment one of the boldest conceptions and most interesting discoveries in the history of science.

Efforts have been made to rob Franklin of the honor of this discovery, but it is one thing to suggest that two phenomena may be identical, and quite another thing to prove it. Dalibard's experiments were undertaken at Franklin's suggestions and hardly preceded his own in date.

These experiments were everywhere repeated, and it soon became evident that they were far from being free from danger. Romas, in June, 1753, during a thunder storm in France, drew flashes of electrical fire ten feet long, from a kite raised by a string 550 feet long. The experiment was accompanied by every evidence of intense electrical tension in the attraction of straws, the sensation of spiders webs over the faces of the spectators, and in the loud reports and roaring sounds, similar to the noise of a large bellows. In August, 1753, Prof. Richmann, of St. Petersburgh, lost his life while engaged in similar experiments. Cavallo, in 1777, in London, obtained enormous quantities of atmospheric electricity by an electrical kite, and noticed that it frequently changed its character as the kite passed through different layers of the air. In telegraph offices during a thunder storm, vivid sparks, often very inconvenient and not without danger, are constantly flowing from the receiving instruments, being induced on the telegraph wires from the atmosphere, during thunder storms. (Henry, Sill. Jour. [2] iii, 25,)

964. **Free electricity in the atmosphere.**—That the atmosphere, besides the combined electricity proper to it, contains also at all times free electricity, is proved by raising an insulated conductor a few feet into the air, as by a long fishing rod, and connecting it with the condenser of the electrometer, the leaves of which will diverge sensibly when there is no sign of any thunder storm. Near the earth, (say within three or four feet,) no evidence of free electricity can be detected, and as we rise in the air, its force constantly increases. Becquerel and Breschet, sent up arrows, attached to a tinsel cord ninety yards long, from the top of the great St. Bernard, while the other end was connected

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What of the telegraph? 964. What is said of free atmospheric electricity? How does height affect its developement?

with the condenser of an electrometer; they found that the gold leaves diverged in proportion as the arrow rose higher.

This phenomenon is most striking during fogs and in cloudy weather, when no lightning is commonly seen. Crosse, of England, had over a mile of insulated wire sustained on poles one hundred feet high above the tall trees of his park, connecting pointed conductors with his laboratory, where he has frequently collected, during a heavy fog, electricity enough to charge and discharge a battery of fifty jars, and seventy-three square feet of coated surface, twenty times in a minute, with a report as loud as that of a cannon.

It appears from experiments like these and others made chiefly by Ronald's, of Kew, that the atmospheric electricity increases and decreases daily, twice in twenty-four hours, and the following general results are established.

1st. The electricity of the air is always positive,—is fullest at night,—increases after sunrise,—diminishes towards noon,—increases again towards sunset, and then decreases towards night, after which it again increases.

2d. The electrical state of the apparatus is disturbed by fogs, rain, hail, sleet or snow. It is negative when these approach, and then changes frequently to positive, with subsequent continued changes every three or four minutes.

3d. Clouds also, as they approach, disturb the apparatus in a similar way, and produce sparks from the insulated conductor in rapid succession, so that an explosive stream of electricity rushes to the receiving pole, which should be passed off to the earth. Similarly powerful effects freqently attend a driving fog and heavy rain.

The subject of atmospheric electricity, especially the description of electric meteors, is more properly referred to meteorology.

DYNAMICAL ELECTRICITY.

GALVANISM OR VOLTAISM.

965. **Discovery of galvanism.**—In 1786, Luigi Galvani, professor of anatomy in the University of Bologna, while engaged upon a long series of observations on the effects of atmospheric electricity upon animal organisms, noticed that the legs of some frogs, prepared for experiments, became convulsed, although dead and mutilated—when the vertebræ, with portions of the lumbar

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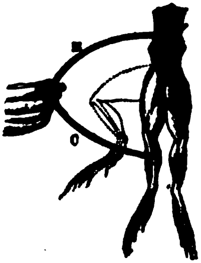
What were Crosse's experiments? What general results follow? 965. Give the history of Galvini's discovery.

nerves, were pressed against the iron railing of the window balcony where they were placed, awaiting the use for which they had been designed. Repeating this novel and curious observation in various ways, he soon found that the convulsions were strongest when he made connection by means of two metals between the lumbar nerves, and the exterior muscles denuded of the skin, as shown in fig. 584, where rods of copper and zinc, being thus held, convulse the leg into the position shown by the dotted line.

584



To repeat Galvini's experiment, strip the skin from the legs of a vigorous frog, and cut the animal in two, an inch above the thighs. Expose the lumbar nerves within and on either side of the back bone, by pushing aside the muscles with the finger, so that the point of an arc of the two metals may touch the nerves; then bring the other metal rod into contact with any portion of the outer surface, and strong twitchings will be developed as if the animal was alive, both on touching and removing the rod, even some hours after death.

Upon this fundamental observation a new science has grown up, that of *dynamic electricity*, or *galvanism*. It is true, Galvani, who was an anatomist and physiologist, and not a chemist or physicist, did not work out all the teachings of his own discovery, being more interested in demonstrating, as he did, the existence of a true animal electricity, developed between the outer surface and the nerves, while he left to others, and chiefly to VOLTA, the physical branch of the subject, devoting the few remaining years of his life to the study of animal electricity, never indeed accepting Volta's doctrines; and dying in 1798, before his pile was given to the world. In this department of vital electricity, his labors have been justly appreciated only in our time, having been naturally eclipsed in his own by the splendid discovery of the voltaic pile, and the crowd of wonders following in its train.

Galvani regarded the convulsions of the frog as excited by a nervous or vital fluid, (*the galvanic fluid*,) which passed from the nerves to the muscles by way of the exterior communication established between them: this fluid, in his view, existed in the nerves, it traversed the metallic arc, and falling on the muscles, it contracted them, like the electric discharge.

The story usually found in text books, of the accidental discovery,

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How is his experiments repeated? Compare what is said of Volta and Galvani. What was Galvani's vital fluid? Give other facts in this history.

in 1790, of the new science by the twitching of frog's legs, prepared for the repast of Madame Galvani, is a fabrication of Alibert, an Italian writer of no repute. Galvani had then been for eleven years engaged upon a laborious series of electro-physiological experiments on this subject, using frog's legs *as electroscopes*. No great truth was ever discovered by *accident*. Years of laborious research had prepared the way to this discovery. It is undoubtedly true that what we find is often more important than what we seek, but it is research and not accident which makes the discovery. Every hypothesis is good which bears fruit in discovery; but to accept the discovery and reject the hypothesis when no longer fruitful, requires all the self-denial of the highest philosophy, and is the peculiar attribute of the greatest minds.

966. **Origin of Volta's discovery.**—Adopting at the outset with the greatest enthusiasm the vitalist hypothesis of Galvani, Volta came, after no long time, to the conviction that the electrical effects attributed by Galvani to the animal electricity of the frog, were really due to *the contact of dissimilar substances*, and that the frogs limbs were only the sensitive electroscope, adapted to indicate the electrical current developed by the two unlike metals. Thus originated his celebrated '*contact theory*;' a view of the source of dynamic electricity, that long held almost universal sway over scientific opinion until gradually supplanted by the *electro chemical theory*, which refers the phenomena to chemical action.

By the use of his condensing electrometer, (944,) Volta sought to establish the contact theory by a great number of well-devised experiments. Being assured of the passive state of the electrometer, he established communication between the earth and the upper plate by the moistened fingers, while at the same time a bit of zinc plate held also in the moistened fingers of the other hand is placed in contact with the lower plate; after a single instant, contact is broken, and on raising the upper plate, the gold leaves diverge. Whence the electricity? Volta replied, 'from the contact of the two unlike substances,' overlooking the fact that there was a chemical action, due to the effect of the moist fingers on the zinc. As the plate touched by the zinc became positive, and the copper negative, he assumed that there was an '*electromotive force*' capable of developing these electrical states in the two metals as a result of *simple contact*. This experiment was repeated with conductors of every sort, and always,

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What is said of discovery by accident? 966. What was Volta's hypothesis? How did Volta seek to establish the contact theory? Whence did he derive the electricity? How did he classify conductors?

when one of them was an alterable substance, with the same results. He divided conducting bodies into two classes; the first class, including the metals, metallic ores and carbon, he calls electrometers; the second class contains liquids, saline solutions, animal tissues, &c. He found that a double combination of three elements, so arranged that their order was reversed, neutralized each other, and produced no spasm in the frogs legs, which he uniformly used as an electroscope. This was in 1796, four years in advance of the date usually assigned as that of the invention of the pile.

Passing over the long controversy between Volta and his cotemporaries, we come to the essential fundamental fact of Volta's discovery, viz: *that certain metals, and particularly the oxydizable metals, disengage electricity and charge the condenser, when placed in the conditions just described.*

This discovery immediately led to the second, and by far the most celebrated of Volta's discoveries, viz., the *voltaic pile, or battery.*

967. **Volta's pile, or the voltaic battery.**—Every form of apparatus designed to produce a current of dynamic electricity is called a *battery* or *pile.* Volta's original apparatus was, as its name implies, *a pile* of alternate silver and zinc discs, laid up as in fig. 585, with discs of paper or cloth between them, moistened with brine, or acid water. This arrangement was more commonly made with alternate discs of copper, (C,) and zinc, (Z,) care being taken always to observe the order, copper—cloth—zinc. The terminal discs were provided with ears for the convenient attachment of wires. Thus arranged, the following characteristic results are observed. 1st. The pile being insulated by glass or resin, touch *z* with the plate of the condenser, (covered with silk,) while the finger rests on *c*, and then apply the plate to the condenser; the gold leaves will indicate strong vitreous electricity. 2d. Reverse this order, touching *c* with the plate while the finger is on *z*, and a strong charge of resinous electricity is received.

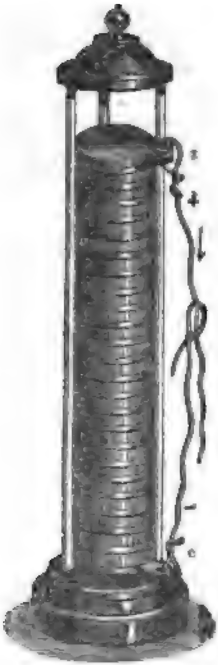
The pile may be regarded as a Leyden jar, or electrical battery, perpetually charged, and capable of re-charging itself as long as the given conditions are maintained.

These results may be repeated an indefinite number of times,

What is the essential fact of Volta's discovery? To what did this lead? 967. What is a pile or battery? Describe Volta's pile.

as long as the cloths remain moist, and the intensity of the action is directly as the number of plates in the pile.

585



Each touching couplet of copper and zinc may be soldered together and is then called a *couple*, *pair*, or *voltaic element*. Any two metals of unlike properties may be substituted for the zinc and copper, with the same results.

The end of the pile which yields vitreous electricity is called its *positive pole*, and that which yields resinous electricity is called the *negative pole ;* a name also applied to the wires or conductors connecting the two poles.

Arranged as in fig. 585, the pile, when its poles are joined, gives a decided shock, similar to, but less intense, than that from statical electricity; and on breaking contact between the poles, a brilliant spark of voltaic electricity is seen; and lastly, if these wires end in points of gold or platina, and are inserted in water, a flow of gas bubbles from them, announces the decomposition of the water; thus grouping the classification of the effects of the pile into *physiological*, *physical*, and *chemical* phenomena.

The discovery of the pile, Volta announced in March, 1800, to Sir Joseph Banks, both in the form just described and also the crown of cups, (Couronne des tasses,) a series of twenty glass goblets arranged in a circle, with wires connecting the + and — elements of each cup to the opposites of the next. This is the type of all modern batteries with separate cells. He classifies its effects, but makes no mention of its power of chemical decomposition. This last power was immediatel yd iscovered by Nicholson and Carlisle, in London, on the 2d of May, 1800.

Aside from Volta's theoretical notions, history will ever assign him

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What effects are noticed by the condenser? How is the pile to be regarded? Explain the terms couple—Voltaic element—and poles. How are the effects of the pile classified? When and how did he announce this discovery? What other apparatus did he also describe at the same time? Who discovered the chemical effects, and when? What is said of Volta?

a high place as a philosopher, and as having by his genius blessed the world by one of the greatest and most fruitful discoveries in science.

968. **Quantity and intensity.**—There is a very marked difference between the tension of the electricity of the Voltaic pile, and that of friction. No sensation follows the touch of either pole of a Voltaic battery alone: both poles must be touched simultaneously in order to perceive the shock. The projectile force, in voltaic electricity is so nearly null, that in the most energetic and extensive series of cells, the terminal points must be brought indefinitely near, or into actual contact, before any current is established. The intensity of the battery is however increased by reduplicating the number of couples of a given size, while the quantity remains unchanged. The *quantity* of electricity set in motion in the Voltaic battery depends not on the number of the series, but entirely on the *extent of surface* brought into action in each pair, and also upon the conducting power of the interposed liquid.

969. **Simple Voltaic couple.**—Whenever two unlike substances, moistened by, or immersed in, an acid or saline fluid are brought into contact, a Voltaic circuit is established. The earliest recorded observation on this subject, (Sulzer's,) was the familiar experiment of a silver and copper coin, or bit of zinc, placed on the opposite sides of the tongue, and the edges brought together, when a sharp, prickly sensation and twinge is felt, and if the eyes are closed, a mild flash of light is also seen. In this case, the saliva is the saline fluid, exciting a Voltaic current due to its chemical effect on the zinc or copper, and the nerves of sense are the eletroscope. The action depends on contact, and ceases as often as this is broken.

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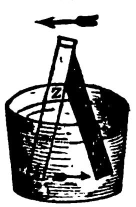

In fig. 586, we have the simplest form of Voltaic battery, a slip of amalgamated zinc, *Z*, and another of copper, *C*, immersed in a glass of water, acidulated by sulphuric acid. When these strips touch, (either within or without the fluid,) an electrical current sets up, passing from the zinc to the copper in the fluid, and from the copper to the zinc in the air, as shown by the arrows. The polarity of the ends in the air is the reverse of that in the acid, as shown by the signs plus and minus. This is in analogy to the decomposi-

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968. What is said of the tension of the Voltaic pile? What of its projectile force? What of quantity and intensity? 969. What is essential to a Voltaic circuit? What was the first observation?

tion of neutral electricity in a rod of glass or of wax. While contact is maintained, either directly or by conducting wires, evidence of chemical action is seen in the constant flow of gas bubbles (hydrogen) from the zinc to the copper, from the surface of which they are given off. This action ceases at any moment when contact ceases, and if the separation of the metals takes place in the dark, a minute spark is seen at the moment of breaking contact.

The direction of the Voltaic current depends entirely on the nature of the chemical action producing it. Thus if in the arrangement just described, strong ammonia water was used in place of the dilute acid, all the electrical relations of the metals and the fluid would be reversed. Since, then, the action would be on the side of the copper, and the zinc would be relatively the electro-negative metal.

970. **Electro-positive and electro-negative** are relative terms, designed to express the mutual relations of two or more elements in relation to each other. Thus zinc, being a metal very easily acted on by all acid and many saline solutions, becomes electro-positive to whatever other element it may be associated with, unless, as in the last section, the other element is acted on, and the zinc is not, when it becomes electro-negative. Oxygen is an element which acts upon every other, and is therefore the type of electro-negative substances; gold, platinum, and silver, being among the least easily oxydized metals, become electro-negative substances to all others more easily acted on than themselves, and therefore are fit substances for the negative element of voltaic couples. In chemical works, tables will be found in which all the elements are grouped in this relative order of electro-positive and electro-negative power.

971. **Amalgamation.**—Commercial zinc is never pure, and the foreign substances which it contains, (carbon, iron, cadmium, &c,) are such as to stand in an electro-negative relation to the zinc. A slip of common rolled zinc, immersed in dilute sulphuric acid, is actively corroded with the escape of abundance of hydrogen, while if a strip of chemically pure zinc was used, no action would happen. (De la Rive.) This action of common zinc is called a *local action*, implying the existence of as many small local Voltaic circuits as there are particles of foreign electro-neg-

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Explain the simple voltaic circuit from fig. 586. Give the polarities in and out of the fluid. What determines the direction of the current? 970. Explain the use of the terms electro-positive and electro-negative. 971. How is commercial zinc affected by acids?

ative substances on its surface; each of which constitutes, with the contiguous particles of zinc, a minute battery, and thus the whole surface is presently corroded and roughened, and the power of the whole couple reduced just in proportion to the extent of this local action.

Rub the freshly corroded surface of such a piece of commercial zinc with a little mercury, when instantly it combines with and brightens the whole surface, covering it with a uniform coating of *zinc amalgam*. This perfectly protects the zinc from local action by covering up the electro-negative points, and makes the whole surface of one electrical name. Zinc, thus *amalgamated*, may be left indefinitely long in acid water, without injury, and when brought in contact with the electro-negative element of a Voltaic couple, it becomes a much more energetic source of electricity than before.

The discovery of this property, (due to Mr. Kempt,) is hardly less important than the discovery of the battery, for without it, sustained and manageable batteries are impossible.

BATTERIES WITH ONE FLUID.

972. **Voltaic batteries** are constructed for use either with one or with two fluids.

The first embraces the original crown of cups, (967,) and all batteries with one fluid and a single cell. The batteries with two fluids and two cells, of whatever name, involve a double chemical decomposition, and are, hence, more complicated, but also generally more efficient; we will consider these separately, remarking, that the interest attached to the first class, with a single exception, is now chiefly historical.

973. **Trough batteries.**—The inconvenience of Volta's original form of the pile, fig. 584, led to placing the elements in a trough, as seen in fig. 587, called, from the inventor, Cruickshank's troughs. Each compound couple of zinc and copper was cemented water tight into a groove, all the zincs facing in one direction. The filling of these cells with dilute acid was a tedious operation, with extended series,

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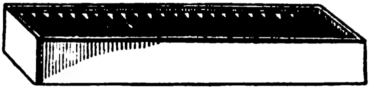

Is pure zinc affected? Why this difference? How is zinc amalgamated, and why? 972. How are batteries classified? 973. Describe the trough batteries, fig. 587 and 588.

and as the zincs were not amalgamated, the best force of the apparatus was spent before it could be filled. Davy and Nicholson greatly improved the trough by attaching the couples to a bar of wood by straps *c o n m*, as in fig. 588, and Dr. Wollaston surrounded each zinc, *z*, with the copper, on both sides, thus doubling the effective surface. Thus arranged, the whole series could be plunged at one movement into glass cells, *a a*, or into a porcelain trough divided into cells. It was with a series of 2000 couples so arranged, each plate having an effective surface of twenty-two square inches, that Davy, in 1806-8, made a series of experiments remarkable in the history of science. This battery was placed in the vaults under the Royal Institution, where its hydrogen and acid vapors did not annoy the experimenter, and its power was led up by conductors to the laboratory.

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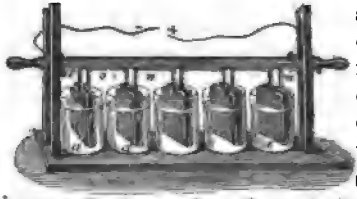

Hare's '*calorimotor* consisted of twenty plates each, of copper and zinc, nineteen inches square, and so constructed in a cubical box as to form but two large elements of fifty square feet each, or two hundred square feet of active surface in both members, all plunged by one movement in a vat of acid.

The *deflagrators* of Dr. Hare as originally constructed were formed of spirals of copper and zinc, rolled with a narrow space between them, and the opposing metals held from contact by wooden strips. Each zinc was 9″ × 6″, and each copper 14″ × 6″; so that every part of the zinc was opposed to the copper surface; eighty of these coils were so arranged on bars of wood as to plunge by an easy mechanism into glass cylinders containing the acid. The facility of immersion and removal of these coils in contact of the acid liquor, made Hare's deflagrators as much superior to the early trough batteries as the batteries of two fluids are superior to Hare's. In a very efficient form of Hare's deflagrator, the members were connected in a box, suspended, to revolve on an axle having another box placed at right angles to the first, so that a quarter revolution of the apparatus, turned on or off the exciting acid at pleasure, without deranging the connections.

A battery constructed for Prof. Silliman, in Boston, in 1836, on the

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What is said of Davy's battery? What are Hare's deflagrators? What other large single cell batteries are named?

plan of Wollaston and Hare combined, contained nine hundred couples of copper and zinc (10″ × 4″ each) exposing five hundred and six square feet of available surface, arranged in twelve parallel series, capable of being used consecutively as nine hundred couples, or in three series of three hundred each. One plunge immersed the whole battery, and when new, the arch of flame between its poles measured over six inches.

Mr. Crosse, and also Mr. Gassiot, have constructed very extended series of trough batteries for physiological experiments; the former had twenty-four hundred pairs of plates, the cells well insulated; the latter put up three thousand five hundred and twenty cylindrical pairs, placed in cells of varnished glass, and insulated by glass pillars varnished. The batteries were excited by water only. Except for the purposes of low intensity and long continued action, batteries of this description are now no longer constructed.

The want of sustained and regular action in all batteries of the original form, has led to the contrivance of other and more scientific batteries; some of the most valuable of which we will now describe.

974. **Smee's battery** is formed of amalgamatic zinc and silver, and needs but one cell and one fluid to excite it. The silver plate, *S*, fig. 589, is prepared by washing in nitric acid to roughen it, and then coating its surface with platinum, thrown down on it by a voltaic current, in that state of fine division, known as platinum-black. This is to prevent the adhesion of the liberated hydrogen to the polished silver. Any surface of polished metal retains a film of gas with singular obstinacy, thus preventing in a measure the contact between the fluid and the plate. The roughened surface produced from the deposit of platinum-black entirely prevents this. The zinc plates *z z* in this battery are well amalgamated, and face both sides of the silver. The three plates are held in position by a clamp *b*, at top, while the interposition of a bar of dry wood, *w*, prevents the passage of a current from plate to plate. Water acidulated with one-seventh its bulk of oil of vitriol, or, for less activity, with one-sixteenth, is the exciting fluid.

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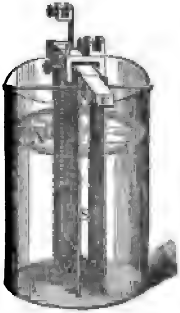

The quantity of electricity excited in this battery is very great, but the intensity is not so great as in the compound batteries presently to be described. This battery is nearly constant, does not

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974. Describe Smee's battery. What is said of its value?

act until the poles are joined, and, without any attention, will maintain a uniform flow of power for days together. A plate of lead, well silvered, and then coated with platinum-black, will answer equally well, and indeed better than a thin plate of pure silver. This battery is recommended over every other for the student, as comprising the great requisites of cheapness, simplicity, and constancy. This is the battery generally employed in electro-metallurgy. Chester has patented an improved form of this battery, much used by the telegraph companies. It is the only single fluid battery now much used in physical experiments.

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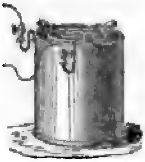

975. The sulphate of copper battery is designed to use a solution of sulphate of copper in dilute sulphuric acid, the copper element being made to contain the exciting fluid. This battery has been a good deal used for electro-magnetic experiments, but it soon becomes incumbered with a pulp of metallic copper thrown down on the zinc.

BATTERIES WITH TWO FLUIDS.

976. Daniell's constant battery.—This truly philosophical instrument was invented in 1836; up to which time the improvements in the original voltaic pile had been only mechanical. Prof. J. F. Daniells, of London, first discovered and applied an effectual means of preserving the power and continuing the action of the apparatus for a length of time. All other batteries with two fluids are only modifications of his. It consists of an exterior circular cell of copper, *C*, fig. 591, which serves both as a containing vessel and as a negative element; a porous cylindrical cup of earthenware, *P*, (or the gullet of an ox tied into a bag,) is placed within the copper cell, and a solid cylinder of amalgamated zinc, *Z*, within the porous cup. The outer cell, *C*, is charged by a mixture of eight parts of water and one of oil of vitriol, saturated with blue vitriol, (sulphate of copper.) Some of the solid sulphate is also suspended on a perforated shelf, or in a gauze bag, to keep up the saturation. The inner cell is filled with the same acid water, but without the copper salt. For the most constant results, he used saturated solution of blue vitriol, made slightly acid for the outer cell, and for the zinc,

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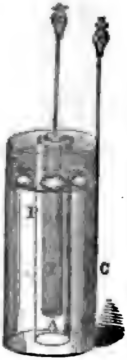

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975. What is the sulphate of copper battery? 976. Describe Daniells' constant battery.

twenty parts water to one acid. Eight or ten hours is about the limit of its constancy. Any number of cells so arranged are easily connected together by binding screws, the *C* of one pair to the *Z* of the next, and so on. The hydrogen from the decomposed water in this instrument is not given off in bubbles on the copper side, as it is in all forms of the simple circuit of zinc and copper; because the sulphate of copper there present is decomposed in the circuit, atom for atom, with the decomposed water, and the hydrogen takes the atom of oxyd of copper, appropriating its oxygen to form water again, while metallic copper is deposited on the outer cell. No action of any sort results in this battery, if the zinc is well amalgamated, until the poles are joined, and it gives off no fumes. Ten or twelve such cells form a very active, constant, and economical battery, and two dozen of such are ample for ordinary uses. Hot solutions increase its power, and the extent of zinc surface, and not the diameter of the copper, limits the amount of electrical effect.

977. **Grove's nitric acid battery.**—Mr. Grove, of London, has successfully applied the principle of Daniell's battery, to produce the most powerful and intense sustaining battery known. The fluids used are strong nitric acid and dilute sulphuric acid, kept apart by a porous jar. The metals are amalgamated zinc, placed in the sulphuric acid of the outer vessel, and platina in the porous vessel: fig. 593, shows this arrangement as complete. The platinum element is seen isolated in fig. 592. The cover, *c*, upon the vase, *V*, fig. 593, tends to keep down the strong vapors of nitrous acid evolved when the battery is in action. The binding screws, *a*, *b*, serve to unite the elements of separate pairs. The zinc here surrounds the platinum, because both that metal and the nitric acid are to be economized as much as possible, being the

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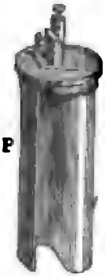

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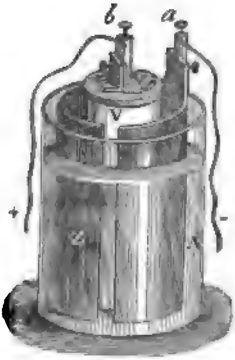

On what does its efficacy depend? 977. What is Grove's battery? Describe its action and theory.

costly parts of the arrangement. From six to ten parts of water are used in *a*, to one of acid.

The action of this battery is intense and splendid. The hydrogen is immediately engaged by the nitrous acid which it decomposes very readily. There is therefore a double chemical action, and an increased flow of electricity, since no part of the power is lost in combination. The fumes of nitrous acid are partly absorbed by the nitric acid, turning it at last intensely green; but enough are evolved to render it important to set the apparatus in a clear space, or good draught. Four cells, with platinum three inches long by half inch wide, decomposes water rapidly; and twenty such cells form a battery giving intense effects of light.

Platinum, in the nitric acid battery, is estimated as sixteen or eighteen times more powerful than copper in Daniells' battery; that is, six square inches of platinum is as efficacious as one hundred square inches of copper; and Peschell found three hundred and forty times as much surface of copper was needed, in a spiral battery on Hare's construction, as of platinum to insure equal effects.

A Grove's battery, constructed by Jacobi, of St. Petersburgh, contains sixty-four platinum plates, each thirty-six square inches surface, or combined, sixteen square feet. This would be by comparison equal to a Daniells' battery of two hundred and sixty-six square feet, or a Hare's battery of about five thousand five hundred square feet. Grove's battery is rather costly, and very troublesome to manage, as are all batteries with double cells and porous cups.

978. **Carbon battery.**—The great cost of large members and extensive series of Grove's platinum battery led Prof. Bunsen, of Marburg, to use the carbon of gas coke as a substitute for the platinum. Prof. Silliman, jr. in 1842, described a battery (see Sill. Jour. [1] xliii, 393, and xliv, 180) in which natural plumbago was used in place of the platina of Grove's arrangement. This was before Bunsen's apparatus was known of in this country.

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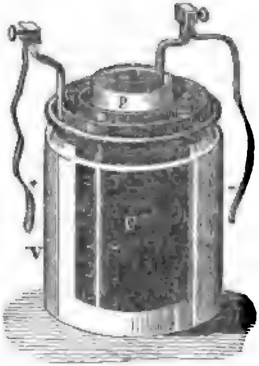

Fig. 594 shows the original form of Bunsen's cells. Where the carbon, *C*, is contained in an exterior vase, *V*, of nitric acid, the amalgamated zinc is in a porous cup, *P*, of dilute sulphuric acid. The objection to this arrangement is the large consumpion of nitric acid and smallness of the zinc. In the au-

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Compare the efficiency of platinum and copper.

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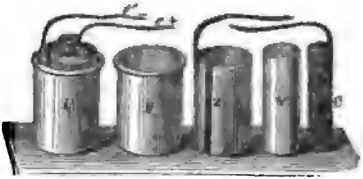

thor's plan, afterwards adopted essentially by M. Deleuil, the carbon was in the porous cup surrounded by the zinc. In fig. 595, this arrangement is shown in detail. *P*, is the pile complete. *F*, is the jar of hard pottery to contain the zinc, *Z*, and the dilute sulphuric acid; *V* is the porous vase, to contain the carbon, *C*, with its nitric acid. The attachment of a conductor to the carbon is accomplished by a conical hole in the centre, into which a plug of hammered copper is crowded with a wrenching motion. If the hard carbon of the gas retorts is used, (it is unquestionably superior,) a copper band is attached to its top by electro-galvanic soldering. The carbon of Bunsen's cells is prepared by pulverizing, and baking in moulds, the coke of bituminous coal. Fig. 596 shows a series of ten cups of the carbon battery arranged for use, the alternate members being joined by binding screws, as made by Deleuil, of Paris, each zinc being twenty-two centimetres, (eight and three-quarter inches) high. As the electro-motive energy of the battery depends on size as well as number, these large members have great advantages. The author demonstrated, in 1842, (*loc. cit.*) that carbon was nearly if not quite as good as platinum surface for surface. A battery of fifty cells, like fig. 596, costs fifty-five dollars in Paris, and with such a series, all the most splendid effects of the electric light, deflagrations, and chemical decompositions can be very satisfactorily shown.

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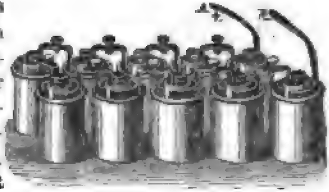

979. **Dry piles of Zamboni and DeLuc.**—These are constructed of discs of metallic paper, as of copper and zinc, (called gold and silver papers,) placed back to back, and alternating as in the pile of Volta, (966,) all the coppers facing in one direction. Sometimes paper gilded on one side and zinc on the other; or zinc paper smeared with black oxyd of manganese and honey on the other side, is used, and with more marked effects. Some hundreds and even thousands of these discs, as large as a quarter dollar, are crowded into a glass tube varnished within

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978. What is the carbon battery? Describe it from fig. 594. Describe the arrangement in fig. 595. What is said of its size, power, and cost?

and without, just large enough to receive them. Screw caps of metal compress and retain the discs, forming at the same time metallic connections with the outer pairs to propagate the electrical effect. A feeble current is thus set up, which may last for years; but if the paper has been artificially dried so as to free it from all absorbed moisture, no current exists.

Zamboni, (1812,) and DeLuc, (1810.) who first constructed piles of this sort, arranged them in pairs to ring bells by the vibration of a small electric pendulum, (fig. 571,) alternately attracted and repelled between the columns, which are in the condition of a perpetually charged Leyden jar of low tension. A set of these bells rang in Yale College laboratory for six or eight years unceasingly.

Bohnenberger's Electroscope is constructed on this principle. *B* and *C*, fig. 597, are the poles of two dry piles, between which hangs a single gold leaf, ending in the knob, *D*. When any feebly electric body is approached to *D*, the gold leaf at once declares its electrical name, by being attracted to its opposite. This is undoubtedly one of the most delicate electroscopes known.

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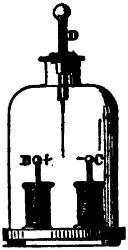

980. **Other voltaic batteries** exist in great variety, but involving no principle not already explained. Some have special adaptation to a particular use, like Chester's form of Smee's battery for telegraphic use; Farmer's copper battery; the battery of Bagration, of zinc and copper in moist earth; or Grove's oxygen and hydrogen gas battery, so instructive theoretically. But further descriptions are excluded by want of space.

POLARITY, RETARDING POWER, AND NOMENCLATURE OF THE VOLTAIC PILE.

980. **Polarity of the compound circuit.**—In batteries of two or more couples, connection is formed, not as in the single couple, (969,) between members of the same cell, but between those of different names in contiguous cells, as in fig. 598, where

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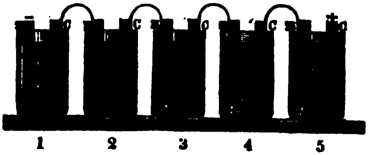

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979. How are dry piles constructed? What of their endurance? How did Zamboni arrange them? What is Bohnenberger's electroscope? 980. What is said of other piles?

the copper of 1 joins the zinc of 2, and so on. The current flows from the zinc to the copper in the fluid, but from the copper to the zinc in the air, (fig. 586,) both in simple and compound circuits. This is important to be remembered, since the zinc is called the electro-positive element of the series, although out of the fluid it is negative. Consequently, in voltaic decompositions, the element which goes to the zinc pole is called the *electro-positive*, and for the same reason, that which goes to the copper is the *electro-negative element*. The terminal plates, *Z* and *C*, in 1 and 5, fig. 598, are not concerned in the electrical effect, being in fact only conductors of the electricity, and hence they may be removed as in fig. 599, without altering the power or nature of the battery. They serve, in fact, merely as a convenient mode of joining the poles, as in fig. 600. The apparent polarity of the simple circuit is therefore the reverse of that of the compound circuit; but an attentive observation of these explanations, and of the figures, will avoid all confusion on this point.

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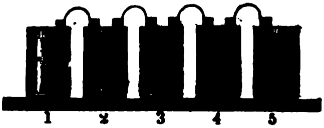

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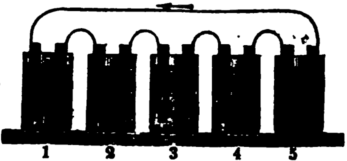
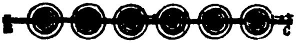


982. **Grouping the elements of a pile** in various numerical relations, is an important means of modifying its power, and the character of its effects, already explained in 968.

Take, for example, six cups, as in fig. 601, arranged in consecutive order, and we have, owing to the resistance to the electric flow, the maximum intense effects possible with such number. Changed to 2 groups of 3 each, and the quantity is doubled, with half of the intensity, fig. 602. In fig. 603, are three groups of two cups each, so arranged as to present three times the surface in 601, with a proportionate loss of intensity. Lastly, in fig. 604, each zinc, and each copper, joins one conmon conductor, each on its own side,

601



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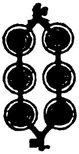

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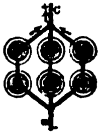

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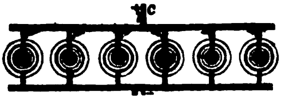

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981. Explain the polarity of the simple and compound circuit.

throwing the six couples into one surface of six-fold extent to 601. The arrangement may be expressed, assuming the resistance of a single cup as unity, thus, 1. $\frac{3}{2} = 1·5$. $\frac{2}{3} = 0·666$. $\frac{1}{6} = 0·166$, and so for any number of couples.

983. **Electrical retarding power of the battery.—Ohm's law.** A certain resistance to the passage of a voltaic current is offered by every additional element placed in the circuit as well as by increased length of conductor. The new properties thus acquired by the compound circuit, have been already alluded to. (908.)

Ohm, of Berlin, in 1827, first demonstrated mathematically the law regulating the flow of electricity in the compound battery. As the apparatus is composed solely of conductors of different retarding power, the electric current must proceed, not only along the connecting wire, from pole to pole, but also through the whole apparatus; the resistance offered to the passage of the current consists therefore of two parts, one exterior to, and one within, the apparatus.

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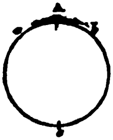
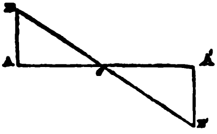


Let the ring, *a b c*, in fig. 605, represent a homogeneous conductor, and let a source of electricity exist at *A*. From this source the electricity will diffuse itself over both halves of the ring, the positive passing in the direction *a*, the negative in *b*, and both fluids meeting at *c*. Now it follows, if the ring is homogeneous, that equal quantities of electricity pass through all sections of the ring in the same time. Assuming that the passage of the fluid from one cross section of the ring to another, is due to the difference of electrical tension at these points, and that the quantity which passes is proportional to this difference, of tension, the consequence is, that the two fluids proceeding from *A*, must decrease in tension the farther they recede from the starting point.

606



This decreasing tension may be represented by a diagram. Suppose the ring in fig. 606, to be stretched out to the line *A A'*. Let the ordinate *A B* represent the tension of positive electricity at *A*, and *A' B'* the negative tension at *A'*, then the line *B B'* will express the tension for all parts of the circuit by the varying lengths of *A B*, *A' B'*, at every point of *A c* or *c A*. Hence Ohin's formula $F = \frac{E}{R}$, where F represents the

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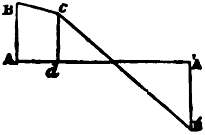
982. How may the elements be grouped, and with what effects? 983. What is said of the retarding power of the battery?

strength of the current *E*, the electromotive force of the battery, and *R*, the resistance. Therefore the greater the length of the circuit, the less will be the amount of electricity which passes through any cross section in a given time. In exact terms, this law states that *the strength of the current is inversely proportional to the resistance of the circuit, and directly as the electromotive force.*

But in the simplest voltaic current, we have not a homogeneous conductor, but several of various powers. To illustrate this, let the conductor *A A'*, fig. 589, consist of two portions having different cross sections. For example, let the cross section *A d* be *n* times that of *d A'*; then, if equal quantities pass through all sections in equal times, if through a given length of the thicker wire no more fluid passes than through the thinner wire, the difference of tension at both ends of this unit of length of the thicker wire must be only $\frac{1}{n}$th of what it is in the latter. Thus, "the electric fall," as Ohm calls it, will be less in the case of the thick wire than of the thinner, as shown by the line *B c* in the figure. The result is expressed in the law that the "*electric fall*" *is directly as the specific resistances of the conductors, and inversely as their cross sections.* Hence, the greater the resistance offered by the conductor, the greater the fall. The very simplest circuit must therefore present a series of gradients expressive of the tension of its various points—as one for the connecting wire, one for the zinc, one for the fluid, and one for the copper. The electro-motive force of a voltaic couple ("E" of Ohm's formula) may be experimentally determined, and is proportional to the electric tension at the ends of the newly broken circuit.

607



984. **Faraday's nomenclature.**—Dr. Faraday has introduced certain terms into the language of electrical science, which are generally adopted for their convenience, and their absence of assumed, or theoretical notions.

Electrode is used in place of *pole*, to which latter term, meaning the terminal wires of a battery, Davy and others seemed to attach a sense as if it possessed a certain attractive force, like the pole of a magnet.—Electrode, (from *electron*, and *odos*, a way,) means simply the way or door by which a Voltaic current enters or leaves a substance.

Anode is that surface of a body receiving the current, or the

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Explain Ohm's theory from figs. 605, 606. State the law. State it for the battery from fig. 607. 984. What is said of Faraday's nomenclature?

positive side of the series, from *ana*, upwards, (as the sun rises,) and *odos*, a way.

Cathode, is that surface of a body from which a current flows out towards the negative side of the series: (from *kata*, downwards, as the sun sets, and *odos*, a way.) The observer is supposed to face the north, with the positive of the battery on his right hand, and its negative on his left.

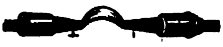
Electrolyte, is any substance capable of separation into its constituents by the influence of a Voltaic series, (from *electron* and *luo*, to set loose.) *Electrolysis*, the act of decomposition. *Electrolyzed*, and *electrolysable*, are obvious derivatives from the same words.

Ions, are the elements into which an electrolyte is resolved by the current. These are either *anions*, elements formed at the positive electrode, or *cations*, ions found at the negative electrode. Hereafter we shall employ these terms when they are appropriate.

THE EFFECTS OF THE VOLTAIC PILE.

985. **The Voltaic spark and arch.**—In 1808, Davy, with the extensive series of two thousand couples at the Royal Institution, first demonstrated the full splendors of the Voltaic arch between electrodes of well-burned charcoal. However powerful the series may be, no effect is in the air seen until the points of the carbon electrodes are brought into actual contact, or at least insensibly near. Herschel noticed that an electrical spark from a Leyden jar, sent through the carbon points, when near each other, established the flow of the voltaic current, by projection no doubt of material particles. When the spark passes, then the electrodes may be withdrawn, as in fig. 608, and the arch of electric flame connects them with a white and violet light of intolerable brightness; several inches in length if the pile is very powerful. This arch of seeming flame is not produced by the combustion of the carbon electrodes, since it exists, with even greater brilliancy, in a vacuum, or in an atmosphere of nitrogen or carbonic acid. M. Despretz states that *in vacuo* with a powerful pile, the voltaic arch may be formed at some centimeters distance, without contact. Fig. 609, shows a con-

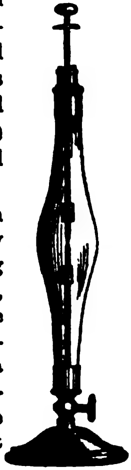
608



Explain Faraday's nomenclature. 985. What is said of the Voltaic arch? At what distance does the spark pass? Describe the Voltaic arch. What is said of its constitution? What origin has it secured?

venient apparatus for this experiment *in vacuo*, or in various gases, as in Davy's original experiments. The Voltaic arch is accompanied by a loud hissing or rushing sound, due to the mechanical removal and transportation of particles of carbon from the positive to the negative electrode by which the former is diminished in length, or made cup-shaped, while the latter is sensibly elongated, as first noticed and described by Prof. Silliman, in 1822, (Sill. Jour. [1] v. 108,) in the use of a powerful deflagrator constructed by Dr. Hare.

609



Through colored glasses, these particles of carbon can be conveniently observed, apparently moving slowly from pole to pole, and giving unquestionably that oval form to the arch, seen in fig. 609, when the electrodes are vertical, and the negative carbon is apparent. There is also distinctly to be seen, a certain structure in zones, or bands of different brilliancy. When the image of the carbon electrodes is projected on a screen, as was first done by Foucault with the electric lantern, the growth of the negative and the decrease of the positive electrode is easily observed, without injury to the eyes. The negative carbon is seen to glow first, as if the light originated there, but as the experiment advances, the positive carbon becomes the most brilliant, and maintains this superiority during the experiment.

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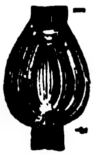

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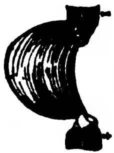

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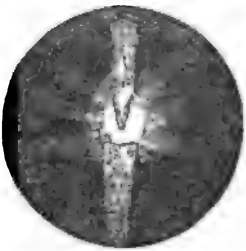

The Voltaic arch is magnetic, or capable of influencing the magnet, by the approach of which it is deflected, as in fig. 612, or even made to revolve with a loud hissing noise; a fact first observed by Davy, but since carefully studied by De la Rive, Quet, and Despretz.

986. **Regulators of the electric light.**—Since the introduction of powerful constant batteries, it has been possible to use the electric light for scientific and economical purposes.

For this purpose *regulators* have been devised to render the light

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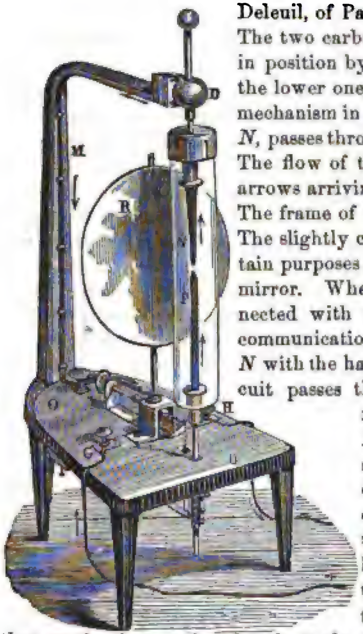
What of the transfer of matter between the electrodes? How may the points be safely observed? Describe the phenomena on a screen? How does the magnet affect the arch?

constant, by approaching the electrodes in proportion as they are consumed. In fig. 613, is shown that of Deleuil, of Paris, and its details, in fig. 613. The two carbon points, *P* and *N*, are held in position by two vertical rods, of which the lower one, *P*, is moved upwards by the mechanism in fig. 614, while the upper one, *N*, passes through the ball, *D*, with friction. The flow of the current is shown by the arrows arriving at *G*, and departing at *H*. The frame of the apparatus is of cast iron. The slightly concave mirror, *R*, is for certain purposes replaced by a large parabolic mirror. When the zinc electrode is connected with *G*, and the carbon with *H*, communication is established by depressing *N* with the hand. As the current in its circuit passes through a coil of wire surrounding the electro-magnet, *E*, fig. 614; the soft iron armature, *m*, on the lever *A*, is drawn up to *E*, so long as the current flows, but if it is interrupted, then *m* falls and the lever *A* is drawn upwards by the spring, *B*, acting against the fulcrum, *L*: the effect of that motion is to raise the electrode, *P*, by a tooth *I*, catching in notches on the upright, *R*. In this way connection is again established; and when this simple mechanism is once adjusted, it will act for hours with great certainty, maintaining the light constant. In Silliman's Chemistry, p. 126, Duboscq's regulator is figured and described, a form of the instrument, well adapted to optical purposes, and called the photo-electric microscope.

613



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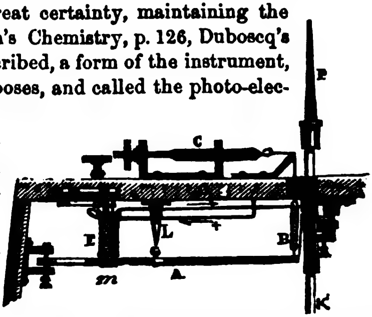

987. **Properties of the electric light.** — Like the solar light, it is unpolarized. It explodes a mixture of hydrogen and chlorine, and acts on chloride of silver, and other photographic preparations, like the sun. Bodies made phosphores-

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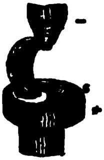
986. Describe the regulator of Deleuil and its action. Figs. 613, 614.

cent by the sun, are similarly affected by the electric light. In 1842, Silliman took Daguerreotypes with it, and it it is now used in preference to solar light, for the purpose of taking microscopic photographs. (Duboscq.)

Fizeau and Foucault, have compared, by photometric measurement, the light from ninety-two carbon couples, arranged in two series of forty-six, (601,) with the solar beam, and also with the oxyhydrogen or Drummond light. In a clear August day, with the sun two hours high, the electric light, assuming the sun as unity, bore to it the ratio of 1 : 2·59, *i. e.*, the sun was twice and a half more powerful, while the Drummond light was only one one hundred and forty-sixth that of the sun. Bunsen found the light from forty-eight elements of carbon, equal to five hundred and seventy-two candles. The intensity of the electric light depends far more on the size of the individual members of the pile than on their number. The effect from forty couples was found by Fizeau and Foucault to be about the same as that from double the number, when the eighty were arranged consecutively, as in fig. 601, while, with the same elements in two parallel series, there was a very great increase of effect. Fraunhofer showed that the spectrum of the electric light was distinguished from that of the sun by a very bright line in the green, and a somewhat less luminous one in the orange. (744.) Dove has lately shown, (Poggendorff's *Annalen*, 1857, No. 6,) that this light has two distinct sources: 1st, the ignition or incandescence of the translated particles, passing in the course of the discharge: 2d, the proper electric light itself. Draper has shown that the spectrum from a glowing platinum wire heated by the battery, contains no lines, so that it is strictly white. (Sill. Jour. [2] viii, 340.) It is not only particles of carbon which pass in the Voltaic arch, but of whatever conductor may form the positive electrode, as platinum, or any metal, and the light varies in its optical properties with every change of the electrode. (Wheatstone.)

615



988. **Heat of the Voltaic arch.—Deflagration.**—When the positive electrode is fashioned into a small crucible of carbon, as in fig. 615, gold, silver, platinum, mercury, and other substances, are speedily fused, deflagrated, or volatized, with various colored lights.

The fusion of platinum (like wax in a candle) before the Voltaic arch is significant of its intense heat, and still more the volatilization and fusion of carbon, a result first announced by Silliman in 1822, and since confirmed by Despretz,

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987. What are the properties of the electric light? What is the comparison with the sun, and drummond light? On what does the intensity depend? What is said of the electric spectrum? What are Dove's and Draper's results?

who, by the union of the heat of six hundred carbon couples arranged in numerous parallel series, and conjoined with the jet of an oxyhydrogen blow-pipe, and the heat of the midday sun, focalized by a powerful burning glass, succeeded in volatilizing the diamond, fusing magnesia and silica, and softening anthracite. The diamond is also softened, and converted into a black spongy mass resembling coke, or more nearly, the black diamond found in the Brazilian mines.

A delicate stream of mercury being allowed to flow from a narrow elongated funnel, (the negative electrode,) upon a surface of mercury in a glass vase forming the positive electrode, is deflagrated with transcendent splendor. Many yards of number twenty platinum wire, held between the electrodes, may be kept in the full glow of white heat for a long time. The teacher can devise many pleasing additional experiments, as drawing the arch beneath water, oil, and other liquids, from points of carbon, or from platinum and steel wires.

When a fine platinum wire is made the positive electrode, and a solution of chloride of calcium, or any other metallic chloride, is made the negative electrode, on touching the surface of the liquid with the point of the fine wire, if the series is powerful the wire is fused on the surface of the liquid, evolving a light of surpassing beauty, whose color is that appropriate to the metal in solution; *e. g.*, from calcium salts, violet-red, from sodium, yellow, from barium, reddish-yellow, from potassium, violet, from strontium, red, &c. These beautiful facts were first noticed by Dr. Hare.

Dr. Page has described a singular motion imparted by the current to globules of pure mercury, placed in a shallow dish, and covered by acidulated water, the globules elongate to ovoids and move actively about, one end, being that towards the + pole, clouded by escaping gas bubbles. If the mercury contains zinc, the position of the clouded end is reversed. (Sill. Jour. [2] xi 192.)

989. **Measurement of the heat of the Voltaic current.**—By means of a long wire coiled into a close spiral, and inclosed in a calorimeter (594,) of glass, containing water, Becquerel and others have established the laws regulating the flow of heat in the electric current, by its effect in elevating the temperature of the water. A coil of platinum wire contained in the bulb of a Sanctorio's thermometer, (507,) becomes a means of estimating the heat of currents too feeble to be otherwise measured. The results are, *that when a voltaic current traverses a homogeneous wire, the quantity of heat in a unit of time is proportional*—

What varies the light? 988. How are the heating effects of the arch shown? What evidences of its heat are given? What happens when a fine platinum wire is deflagrated from liquid surfaces? What of Voltaic motions? 989. How is the heat of the Voltaic arch measured?

1. *To the resistance which the wire opposes to the passage of the electricity :*

2. *To the square of the intensity of the current.* The intensity of a current is measured by the quantity of water which it will decompose in a given time.

For a given quantity of electricity, the elevation of temperature at different points on a conducting wire, is in the inverse ratio of the fourth power of its diameter.

Draper has applied the co-efficient of expansion to determine the degree of heat corresponding to a particular color. (519.)

990. **The chemical effects of the pile** are most wonderful, and the present advanced state of chemical science is largely attributable to the flood of light shed by the researches of Davy and Faraday upon the electrical relations of the elements and the decomposition of compounds by the Voltaic circuit.

In 1800, immediately after Volta's announcement to Sir Joseph Bank's (967) of his discovery of the pile, Messrs. Nicholson and Carlisle, constructed the first pile in England, consisting of thirty-six half crowns, with as many discs of zinc and pasteboard, soaked in salt water. Observing gas bubbles arise when the wires of this pile were immersed in water, Nicholson covered them with a glass tube filled with water, and on the second of May, 1800, completed the splendid discovery, that the Voltaic current had the power to decompose water and other chemical compounds. Stimulated by so fine a result, chemists and physicists everywhere repeated the experiment, perfecting the methods of obtaining both the oxygen and the hydrogen gases in a separate condition. The chemical theory of the pile, originally advanced by Fabbroni, a countryman of Volta's, some years before, was taken up and ardently advocated by Davy, who, in 1801, had succeeded to a place in the laboratory of the Royal Institution: where, on the 6th of October, 1807, he made, by the Voltaic pile, the memorable discovery of potassium, the metallic base of potassa, before regarded as a simple substance; and soon after established the startling truth that all the earths and alkalies, until then esteemed simple substances—the whole crust of the globe in fact—were oxyds of metals, whose existence had hitherto been unsuspected.

991. **Electrolysis of water.—Voltameter.**—The Voltaic decomposition, or electrolysis (984) of water is the finest possible illustration of the chemical power of the pile. Water is a compound of oxygen and hydrogen gases, in the proportions of one

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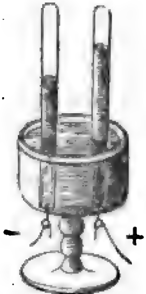
Give the resulting laws? 990. What is said of its chemical effects? Who first observed them? What is said of Davy's results?

measure of the former to two of the latter. When two gold or platinum wires are connected with the opposite ends of the battery, and held a short distance asunder in a cup of water, a train of gas-bubbles will be seen rising from each and escaping at the surface. If the electrodes are not of gold or platinum, the oxygen combines with them, and only hydrogen escapes, as in Nicholson's original experiment. With two glass tubes placed over the platinum poles, fig. 616, we can collect these bubbles as they rise. The gas (hydrogen) given off from the negative electrode is twice the volume of that obtained from the positive. When the tubes are of the same size, this difference becomes at once evident to the eye. By examining these gases, we shall find them, respectively, pure hydrogen and oxygen, in the proportion of two volumes of the former to one of the latter. Agreeably to principles already explained, (981,) the oxygen (electro-negative) appears at the + electrode, and the hydrogen (electro-positive) appears at the — electrode. The rapidity of the decomposition is greater when the water is made a better conductor, by adding a few drops of sulphuric acid; and for rapid electrolyses the number of couples in the series should be increased to overcome, by superior tension, the low conducting power and chemical affinity of the electrolyte. If a single tube only covers both electrodes, as in fig. 617, the total electrical effect is easily measured by the graduation of the tube, the quantity of gases given off in a unit of time being directly as the current.

616



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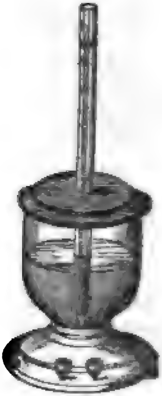

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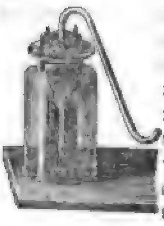

The contents of this tube will explode if a lighted match is applied to them, or if an electric spark passes through them. Such an instrument is a *Voltameter*. A convenient form of this instrument is seen in fig. 618, made of a common bottle filled with acid water; the platina electrodes pass through the cork and end in two plates of platina, while a bent gas tube of glass conveys off the accumulating gases as fast as they are evolved by the electrolysis.

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990. Describe the electrolysis of water. What is a Voltameter?

992. **Laws of electrolysis.**—From a great number elaborate experiments, the accuracy of which remains unshaken, Faraday has deduced the following general laws of electrolysis.

1st. The quantity of any given electrolyte, resolved into its constituents by a current of electricity, depends solely on the amount of electricity passing through it, and is independent of the form of apparatus used, the size or dimensions of the electrodes, the strength of the solution, or any other circumstance. Hence, the amount of water decomposed in a given time in the Voltameter, is an exact measure of the quantity of electricity set in motion.

2d. In every case of electrolysis, the elements are separated in equivalent or atomic proportions, and when the same current passes in succession through several electrolytes in the same circuit, the whole series of elements set free are also in atomic proportions to each other. Faraday hence infers that the amount of electricity required to resolve a chemical combination, is in constant proportion to the force of chemical affinity by which its elements are united.

3d. The oxydation of an atom of zinc in the battery, generates exactly so much electricity as is required to resolve an atom of water into its elements. Thus 8·45 grains of zinc dissolved in the battery, occasions the electrolysis of 2·35 grains of water. But these numbers are in the ratio of 32·5 : 9 the equivalents, respectively, of zinc and of water. Hence follow these corollaries: *First,* that the source of Voltaic electricity in the pile is chemical action solely. *Secondly,* that the forces termed chemical affinity and electricity, are one and the same.

One or two additional illustrations of these laws will be instructive here.

993. **Electrolysis of salts.**—In the bent tube, *B A*, fig. 619, put a solution of any neutral salt; *i. e.*, sulphate of soda, and diffuse the blue tincture of a purple cabbage in the liquid. Let the current of a Voltaic pile communicate with this saline solution by two platinum wires, dipping into the legs of the tube—presently the blue color of the solution is changed on the positive side for red, and the negative for green, indicating the presence of an acid set free in *A*, and of an alkali in B. If the action is kept up, the whole of the blue liquid is changed to red and green.

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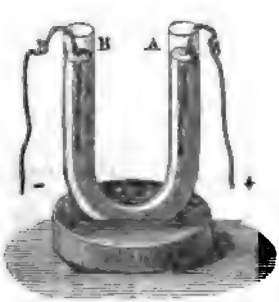
992 Who established the laws of electrolysis? What is the first law? What is the 2d law? What the 3d? Illustrate these. What corollaries follow? 993. Describe the electrolysis of salts.

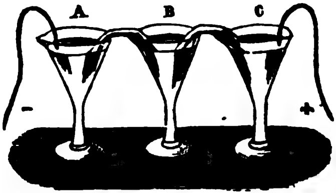
Transpose, then, the + and — wires, so as to reverse the direction of the current; presently the red and green change back to blue, and in a short time that which was red becomes green, and *vice versa*. This is a case of electrolysis in which the electrolyte (sulphate of soda) is changed, not into its ultimate elements, but only into the acid and alkali, which may be called its proximate constituents; any other saline fluid may be substituted with similar results. If an alkaline chloride is used, *i. e.*, common salt, the free chlorine revolved on the + side, discharges all color, while the soda produces on the — side its appropriate green tint. If a metallic salt, *e. g.*, sulphate of copper, or acetate of lead, is used in *A B*, then on the — side, metallic copper or lead is evolved, while on the + side is the free acid before in combination in the salt.

619



A more surprising example of the apparent transfer of elements under the power of the Voltaic current is illustrated in fig. 620, where in the center glass, *B*, of the three wine glasses, *A B C*, is a solution of sulphate of soda, while *A* and *C* contain only pure water, blued with cabbage tincture. Filaments of moist cotton wick connect the three glasses, and the electrodes are introduced into *A* and *C*, when the same series of changes, already described in fig. 619, take place, with the same reversals when the electrodes are transferred. *B* remains apparently unchanged while *C* is reddened and *A* becomes green, or *vice versa*. There is in fact nothing more wonderful in this case than in the last, only the dissection of the process into three parts, makes the result still more striking. In place of *A*, *B*, *C*, any number of glasses, with different salts and compounds, may be substituted, with results conformable to the law in 992.

620



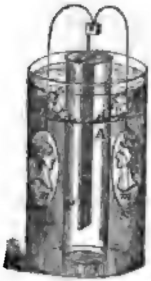
994. **Electro-metallurgy.—The electrotype.**—The cold casting of metals by the Voltaic current, is a fine example of the rich gifts made by abstract science to the practical arts of life.

Give a more surprising example with three glasses, fig. 620.

Every Daniell's battery is in fact an electro-metallic bath, in which metallic copper is constantly thrown down from solution, of a firm and flexible texture.

The very simple apparatus required to show these results experimentally, is represented in the fig. 621. It is nothing, in fact, but a single cell of Daniell's battery. A glass tumbler, *S*, a common lamp-chimney, *P*, with a bladder-skin tied over the lower end and filled with dilute sulphuric acid, is all the apparatus required. A strong solution of sulphate of copper is put in the tumbler, and a zinc rod, *Z*, is inserted in *P* ; the moulds, or casts, *m m*, are suspended by wires attached to the binding screw of *Z*. Thus arranged, the copper solution is slowly decomposed, and the metal is evenly and firmly deposited on *m*, *m*. A perfect reverse copy of *m* is thus obtained in solid, malleable copper. The back of *m* is protected by varnish, to prevent the adhesion of the metallic copper to it. In this manner the most elaborate and costly medals are easily multiplied, and in the most accurate manner. In practice, reverse casts are made in fusible metal or wax of the object to be copied, and the operation is conducted in a separate cell, containing only the sulphate of copper, one of Smee's batteries supplying the power. The art is now extensively applied to plating in gold and silver from their solutions ; the metals thus deposited adhering perfectly to the metallic surface on which they are deposited, provided these be quite clean and bright.

621



Even alloys, as bronze, brass, and German silver, may be deposited according to electrolytic law.

The positive electrodes should be of the same metal as that in solution, and as large as the surfaces to be coated, and these should not be larger than the plates of the battery furnishing the current. Wood cuts and printers' types are thus copied in copper, the moulds taken in wax from them being made conductors by dusting over the surface with extremely fine plumbago. All the copper-plates of the charts of the Coast Survey are reproduced by the electrotype—the originals are never used in the press, but only the copies, and any required number of these may be produced at small expense.—For an instructive account of these extensive electrotype operations, the student is referred to an elaborate paper by the Electrotypist of the Coast Survey, Mr. G. Mathiot, (Sill. Jour. [2] xv, 305,) in which the law of Ohm (983) is applied to determine the electrical conditions of this important practical problem.

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994. Describe electro-metallurgy, or the electrotype. 995. What is said of the deposit of metals by other metals? Give the examples.

995. Metals deposited from solution by the presence of another metal.—It was known to the alchemists, very early in chemical history, that certain metals, as gold, silver, copper, lead, tin, &c., were deposited in a pure, or '*reguline*' condition, from their solutions, when another metal was present, or even sometimes without that condition. Thus the lead tree, (*arbor Saturnæ*,) the tin tree, (*arbor Jovis*,) the silver tree, (*arbor Dianæ*,) were so called by the alchemists, from the apparent growth of these metals out of their solutions, and in tree-like forms. This growth we now know to be Voltaic deposition.

A solution of chlorid of gold in ether, by slow change, deposits spontaneously, crystals of fine gold, in elegant moss-like growths; and Liebig has shown us how to prepare a silver solution, which, by the aid of an essential oil as a reducing agent, will coat glass with a film of silver so thin as to be transparent, and still so brilliant as to reflect light more perfectly than the best mercurial mirrors.

A dilute solution of acetate of lead, (half an ounce to a quart of rain water,) surrenders all its lead to a strip of zinc hung in the containing bottle, in elegant crystalline plates; (*the arbor Saturnæ*;) this, and the next case, are true Voltaic circuits, while in the two first cases, hydrogen appears to supply the want of the second element of Voltaic couple. In like manner, a dilute solution of nitrate of silver, placed over mercury, soon deposits all its silver in an arborescent form (*arbor Dianæ*) on the mercury.

But the most instructive case of this kind is when a bar of pure tin is placed upright in a tall vessel, the lower half of which is filled with a saturated solution of protochlorid of tin, while above it rests a dilute solution of the same salt. The bar is therefore in two solutions chemically identical, but physically unlike. The result is a Voltaic current, by which metallic tin, in beautiful brilliant plates, is deposited upon the upper part of the bar, while the lower part is correspondingly dissolved by the free electro-negative element of this electrolysis.

996. **Deposit of metallic oxyds and Nobili's rings.**—E. Becquerel has shown that oxyd of lead and oxyd of iron may be deposited in a thin film on the surface of oxydizable metals by using an alkaline solution of the metallic oxyd, and making the plate to be oxydized the negative electrode of a constant battery; a deep brown coating of the oxyd is thus deposited in a few minutes so firmly as to withstand the action of the burnisher, and perfectly protect the iron or steel from atmospheric action.

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996. What is said of the deposit of metallic oxyds—Nobili's rings?

If the film of oxyd of lead is very thin, it presents, over a surface of polished silver or steel, a most pleasing exhibition of colored rings, analogous to the colored rings of Newton from thin plates, (837). For this purpose the negative electrode is made of a thin platinum wire, protected from the solution by a glass tube, except at the extremity, where a mere point is presented. A rim of wax on the edges of the plate retains the solution of potassa, saturated with oxyd of lead, while it is connected on the positive pole, and the negative point is held for a few seconds within a line of the polished surface. These colored rings were first noticed by Mr. Nobili, whence their name.

997. **The physiological effects of the Voltaic pile.**—Galvani's original experiment, (965,) and the earlier observations of Swammedam and Sulzer, of two metals on the tongue, (969,) deserve to be remembered as being our earliest knowledge of this subject. From a small number of pairs, the dry hand grasping the electrodes, receives no sensation; number, and not size of elements, is requisite for the physiological effect. But from a column of fifty elements, (966,) or still more from fifty cups of Bunsen, a smart twinge is felt, reaching to the elbows, or if the hands are moistened with saline or acid water, the shock will be felt in the shoulders. This shock is unlike the sharp and sudden commotion from statical electricity, being a more continued sensation, accompanied, during the continuance of the current, by a sense of prickly heat on the surface. But it is only at the making and breaking of contact that a *shock* is felt. If the battery contains some hundreds of couples actively excited, the shock becomes painful, or even fatal. It may be passed through any number of persons whose moistened hands are firmly joined, but it is sensibly less acute at the middle of such a circuit than to those at the electrodes. Even after death, this power produces spasmodic muscular contractions, efforts to rise, and contortions of the features frightful to behold. Persons in whom animation was suspended, have been restored by the influence of the hydro-electric current on the nervous system. When the current follows the ramifications of the nerves, the effect is greater than when it is reversed, an important circumstance in the medical application of this power, for which subject, reference may be had to the works Dr. Wm. F. Channing, and of Dr. G. Bird.

The senses of sight, hearing, and taste, are all effected by a Vol-

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997. What are the physiological effects of the pile? How after death? What senses does it affect? Has it an effect on vegetables?

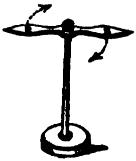
taic current; a flash of light, a roaring sound, and a sub-metallic savor being received when the shock of a small battery is passed, successively, through the eyes, the ears and the tongue.

From the experiments of E. Becquerel, it appears that seeds subjected to a gentle electric current, germinate sooner than otherwise. Von Marum, observed that plants with a milky juice, like the *Euphorbiaceæ*, do not bleed after a powerful electrical shock, owing, he suggests, to the loss of contractile power in the plant.

Certain animals, as the Surinam eel, (*Gymnotus electricus*,) and the torpedo, or *numb-fish*, found on our coast, possess, in their organization, a high electrical power, and are perpetually charged electrical batteries.

998. **The magnetic and electrical effects of the pile,** belong to the subject of *electro-dynamics*, presently to be considered separately. It is sufficient now to state the fundamental fact of electro-magnetism; namely, that a conductor over which a Voltaic current is passing, affects a freely suspended needle, as another magnet would do. If the current flows from the + to the — of the battery, (*i. e.* from S. to N.,) over a magnetic needle, the austral or N. pole of the magnet invariably turns to the left, as in fig. 622. The further consideration of this important and deeply interesting subject is reserved for the chapter on *electro-dynamics*.

622



The electrical effects of the pile have been alluded to in sections 966, 967, and 979.

THEORY OF THE PILE.

999. **Three views.**—*a.* It has already been stated, (966.) that Volta and his school ascribed the effects of the pile to the simple contact of unlike metals, each decomposing the neutral electricity of the other, and arguing that the chemical action of the battery was requisite only to afford conductors for the electricity, while the metallic substances remain in every way unchanged,—they are supposed to discharge into each other. According to this hypothesis, the two metals are in opposite electrical states, one being positive, the other negative, these states becoming at once destroyed by the intervening fluid. This theory assumed

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998. What are its magnetic and electrical effects? 999. What three rules of the pile are here named?

that the whole effect of the apparatus, is but a disturbance and reproduction of electrical equilibrium. It cannot be maintained in this sense, for otherwise, there must be assumed the production of a continual current, flowing on against a constant resistance without any consumption of the generating force.

b. On the other hand Fabbroni, Davy, Wollaston, and above all in our day, Faraday, De la Rive and Becquerel, have sought to establish that the Voltaic excitement was only the reciprocal of the chemical action and as this was more intense, and porperly directed, so was the pile more powerful. In addition to the statements and arguments already adduced, it is proper here to consider the ground of these two views, and somewhat more in detail.

c. A third view or theory of the pile has been advanced by M. Peschell, which he calls the *molecular theory*, and which rests on a sort of middle ground between the contact and the chemical theories.

1000. **Volta's contact theory.**—The advocates of this mode of explaining the action of the pile, (embracing nearly the whole body of the German physicits,) contend that they have experimentally established the following points in support of Volta's theory, viz: 1st, that Volta's original experiments demonstrate the fact beyond question, that the simple contact of heterogeneous metals does produce an electrical current. (966.) 2d, that in some cases when a purely chemical action exists between a fluid and one of the two metals immersed in it, that the contact of the metals arrests this action, and an opposite action commences. 3d, that there are even cases of hydro-electric combinations, in which electrical action exists, without any chemical action whatever on the electromotors. 4th, the advocates of this view further contend that chemical action is never the primitive cause of electrical excitement; although some do not question the influence of chemical action in promoting and increasing the excitement originally due to contact.

Since scarcely any chemical action, or none at all, occurs in a constant battery without contact, it is, with reason, urged that contact of the heterogeneous metals is the one indispensible prior cause of the Voltaic current. Hence the real difficulty seems to be, to decide what share chemical influence really has in exciting the eletrical action. Want of space prevents our

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1000. State the claims of Volta's theory.

giving the evidence in detail upon which the advocates of the contact theory rely for the support of the above propositions.

1001. **The chemical theory** assumes the electrical current to be the reciprocal of the chemical action in the cells of the battery, and that chemical action is essential to the production of such a current.

M. De la Rive demonstrated this latter point in the following manner. A pair, formed of two plates, one of gold, the other of platinum, was plunged into pure nitric acid, without the development of any current; by the addition to the nitric acid of a single drop of clorohydric acid, a very decided current was obtained from the gold to the platinum through the liquid. In the first case there was no chemical action, in the second case, the gold was attacked, and the platinum was not, or was less attacked.

The laws of electrolysis, first demonstrated by Faraday, as already stated, (992,) lend the evidence of mathematical certainty to the chemical theory of the pile. Since we thus reach the unavoidable conclusion that an equivalent of electricity is a chemical equivalent, and so bring the discussion down to the rigid test of the balance, the *ultima ratio* of chemists and physicists.

In addition to the laws of Faraday, already rehearsed, are the following—

1002. **Laws of the disengagement of electricity by chemical action**, first stated by M. Becquerel.

1st. In the combination of oxygen with other bodies, the oxygen takes the electro-positive substance, and the combustible the electro-negative.

2d. In the combination of an acid with a base, or with bodies that act as such, the first takes the positive electricity, and the second the negative electricity.

3d. When an acid acts chemically on a metal, the acid is electrified positively, and the metal negatively: this is a consequence of the second law.

4th. In decompositions, the electrical effects are the reverse of the preceding.

5th. In double decompositions, the equilibrium of the electrical forces is not disturbed.

1003. **The quantity of electricity required to produce chemical action** is enormous, compared with the amount of statical

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1001. What does the chemical theory assume? What is De la Rive's demonstration? What basis do Faraday's results give? 1002. Give Becquerel's five laws.

electricity disturbed by the common frictional machine. Faraday has, in his masterly way, demonstrated this fact by a simple experiment.

He has shown that the quantity of voltaic electricity requisite for decomposing one grain of water, would be sufficient to maintain at a red heat, (during three minutes forty-five seconds, the time requisite to effect the perfect decomposition of the grain of water,) a wire of platinum one one hundredth of an inch in diameter. The quantity of frictional electricity required to produce the same effect, would be that furnished by eight hundred thousand discharges of a battery of Leyden jars, exposing three thousand five hundred square inches of surface, charged with thirty turns of a powerful electrical machine.

M. Becquerel, by a different mode of experiment, arrived at nearly the same results. Therefore, to decompose a grain of water, requires an amount of electricity equal to that furnished by the discharge of an electric pane having a surface of thirty-two acres. 'Equal to a very powerful flash of lightning'. 'This view of the subject gives an almost overwhelming idea of the extraordinary quantity of electric power which naturally belongs to the particles of matter'. (Faraday Expt. Res., 853—861.)

1004. **Polarization and transfer of the elements of a liquid.**—The electro-chemical theory has been much expanded by the researches of M. De la Rive; he explains the phenomena of polarization and the transfer of the elements of a liquid in the following manner.

His theory assumes that every atom has two poles, contrary, but of the same force. The different kinds of atoms differ from each other in that some have a more powerful polarity than others. When two insulated atoms are brought near each other, they attract each other by their opposite poles; the positive pole of that which has the strongest polarity unites with the negative pole of that which has the feeblest polarity. A compound atom, when insulated, has therefore two contrary polarities between the poles of a pile; for example, the atom is so arranged that its + pole is turned to the platinum, (or — side,) of the pile, and the — pole is turned to the zinc, (or + side,) of the pile.

This same action occurs with other atoms, so that there is produced a chain of polarized particles between the poles of the pile.

1003. Illustrate the quantity of electricity required to produce chemical action. 1004, What is said of the polarization of the elements of a liquid ?

The oxygen of the particle of water nearest the zinc, becomes negative, because of its affinity for the zinc, and the hydrogen becomes positive. The other particles of water become similarly electrified by induction, but the platinum has become negative by induction from the zinc, and therefore is in a condition to take up the positive electricity from the zinc of the contiguous hydrogen. The action now rises high enough for the zinc and the oxygen to combine chemically with each other. The oxyd of zinc thus formed dissolves in the liquid, (dilute sulphuric acid,) and is thus removed. But the particle of hydrogen nearest the zinc, now seizes the oppositely electrified oxygen of the adjacent particle, producing a fresh atom of water. The particle of hydrogen which terminates the flow is electrically neutralized by the platinum, to which it imparts its excess of positive electricity, and escapes in the form of gas; and other particles of water are continually produced, to supply the place of those decomposed, and thus continuous action is maintained. These changes, continually taking place, furnish an uninterrupted flow of electricity, which is conveniently termed a Voltaic current.

Other instances of electrolysis are explained in a similar way.

1005. **Chemical affinity and molecular attraction distinguished.** According to De la Rive, and in support of the view of the polarity of atoms, the distinction between chemical affinity and molecular attraction is as follows: chemical affinity is the attraction of atoms, operating by their contrary electric poles, which come into contact, while physical attraction results from the mutual attractive action that the atoms exercise over each other in virtue of their masses. This last attraction is never able to produce contact, because of the repulsive force of the ether which envelops the atom, and which increases in proportion as the sphere which separates the attracted atoms diminishes.

1006. **Theory of Grotthuss for electro-chemical decompositions.**—Grotthuss, who wrote on the pile in 1805, in accordance with the then prevailing notions of the electrodes being *poles of attraction* and *repulsion*, like that of a magnet, conceived the pole from whence resinous electricity issues, as attracting hydrogen and repelling oxygen, while that from which vitreous electricity issues, attracts oxygen and repels hydrogen.

So when the force of a battery reaches a point adequate to the electrolysis of water, the particle of water, *s*, fig. 623, has its — oxygen attracted towards the + pole, while its two atoms of hydrogen

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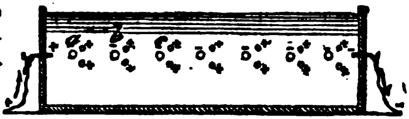
1005. Distinguish chemical affinity and molecular attraction. 1006. What was the theory of Grotthuss?

are repelled towards those whose oxygen parts under this electrical attraction from its own atoms of hydrogen, to join the oxygen of *a*, producing a new atom of water, while *c* in its turn sends its oxygen to join the hydrogen of *b*, and so on to the end of the series, when, finally, arriving at the other electrode, the hydrogen having no new atom of oxygen to join, it is given off at the anode, while the oxygen appears at the cathode. He conceives a similar succession of decompositions and re-compositions to occur in every electrolyte, metallic salts, and oxyds, and thus explains why, in the decomposition of salts, the middle glass (993) is neither reddened or made green.

623



1007. **Peschell's molecular theory of the pile.**—Resting upon the opinion long held by many chemists, that those forces which lie at the basis of adhesion, and those which cause chemical affinity are not essentially different, Peschell holds that—*when electricity is generated in any Voltaic arrangement, it results from a molecular change, brought about in the touching bodies by the adhesive force which subsists between them.*

This theory possesses the advantage, that no new power need be assumed to exist, whereas the contact theory demands the existence of an '*electromotive force,*' of which we know nothing. It also accounts for the production of electricity, apart from any chemical action. In common with the chemical hypothesis, it deduces the phenomena of the single battery from the molecular forces; it considers the fluid not merely as a conductor of electricity, but as engaged in its production, and that the elements of the battery, by the physical changes which they undergo, are the actual sources of electricity; that their contact renders this change possible, and it is, therefore, the occasion, and not the generating cause, by which the electricity is produced. By this view, the chemical hypothesis is only a special case of the molecular. The simultaneous commencement of chemical action with the development of electricity, and the circumstance that the chemical intensity of a simple Voltaic arrangement increases and decreases as the chemical action on the fluid conductor, and on the elements of the battery is greater or less, fully accords with the statements of this theory. It follows, hence, that the electrical and molecular force are one and the same, and that the latter appears as electricity whenever it passes from one mode of operation

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1007. Give Peschell's molecular theory. In what respect does it sustain the chemical view?

into the other, as, *e. g.*, when it ceases to hold the elements of the water, and so oxydizes the zinc.

ELECTRO-DYNAMICS, OR ELECTRO-MAGNETISM AND MAGNETO-ELECTRICITY.

1008. **General laws.**—Electro-dynamics is that department of physics devoted to the mutual action of electric currents, which are wholly unlike the phenomena of static electricity. The phenomena of electro-dynamics may all be arranged under the following general propositions.

1. Every conductor, conveying a current of electricity, affects a free needle as a magnet would do.
2. Electric currents affect each other like magnets.
3. A magnet acts upon an electric current as a second current would have done.
4. Electric currents in conductors excite similar currents in other conductors within their influence.
5. Magnets excite electric currents, and all the electrical effects depending upon them.

Hence, when magnetism is excited by electric currents, it is called *electro-magnetism:* and inversely, when electrical currents result from magnetism, they are called *magneto-electrical currents.*

It is impossible, in our narrow limits of space, to consider each of these heads in detail. We shall endeavor, however, to present those phenomena and their applications which are of most general interest.

1009. **Œrsted's discovery.**—In 1819–20, Prof. Hans Christian Œrsted, of Copenhagen, in a course of researches upon the relation of the Voltaic apparatus to the magnet, made discovery of the fundamental fact of the electro-magnetism, already noticed (996.) Many physicists had before sought to evolve the phenomena of magnetism from the battery; but in vain, because they proceeded without connecting the poles by a conductor, in which case, of course, (as we now clearly see,) the power of the apparatus is dormant, like stagnant statical electricity in an unexcited conductor. *Œrsted closed the battery circuit by a conductor, and therein exactly rests his discovery.* He found when such

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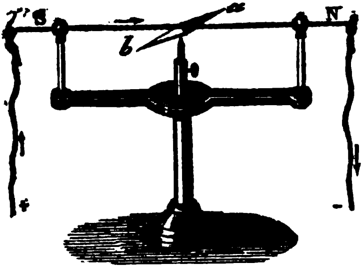
1008. What is electro-dynamics? What are its general laws? What two sub-divisions are named? 1009. What was Œrsted's discovery? On what did it depend?

a conjunctive wire was approached to a free needle, that the needle was influenced by it, as if he had used a second magnet: in other words, the conducting wire, of whatsoever metal it might happen to be, had itself become a magnet.

If positive electricity flows from south to north over a horizontal conducting wire, placed in the magnetic meridian, then a free magnetic needle, *b a*, fig. 624, would have its north end, *b*, deflected to the *west*, if it is placed *below* the conducting wire, and to the *east* if it is placed *above* the wire. If the needle is placed on the east side of such a conductor, its *north end is depressed*, if on the *west side* of the wire, the north end of the needle *is raised*. Reversing the direction of the current, reverses all these movements.

624



Œrsted also found that only needles of steel or iron were thus affected, and not those of brass, lac, and other non-magnetic substances. He called the conductor a "*conjunctive wire*," and he describes the effect of the electric current, (or the 'electric conflict' as he calls it,) as *resembling a helix;* and that it is not confined to the wire, but radiates an influence at some distance.

The effect of Œrsted's discovery was truly electric. The scientific world was ripe for it, and the truth he thus struck out was instantly seized upon by Arago, Ampère, Davy, and a crowd of philosophers in all countries. The activity with which this new field of research has been cultivated, has never relaxed, even to this hour; while it has borne fruit in a multitude of important theoretical and practical truths, and above all, in the ELECTRO-MAGNETIC TELEGRAPH, one of the great features of this age.

1010. **The influence of the electro-magnetic current excited at right angles to the course of the conjuctive wire.**—Let a current flow over a conductor in the direction of the arrow, fig. 625, from + to —; a small bar of iron, or a sewing needle, held vertically before this wire, becomes instantly a magnet, with its *N.* pole toward the earth—place the rod of iron on the opposite side

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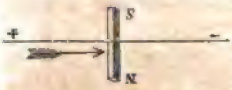
Explain the action of the conjuctive wire. What further is said of this discovery? 1010. How is the influence of the current exerted?

of the conjuctive wire, and its polarity is instantly reversed. Revolve it in either position in a vertical plane at right angles to the conjunctive wire, and the induced poles will retain their relation to the current in every position; *i. e.*, the end marked north in the figure, will remain north at every point of the revolution. If a steel needle is used, it retains polarity after the current ceased to act on it. If the bar or needle be laid parallel to the conjuctive wire, then the *two sides* of the needle or bar have opposite polarities.

625



Hence it follows that a free magnetic needle tends to place itself at right angles to the path of an electro-magnetic current traversing a conjunctive wire, and were the needle free from the directive tendency of terrestrial magnetism, it would so place itself. The electro-magnetic current is therefore a ***tangential*** force, and acts tangentially upon a free needle.

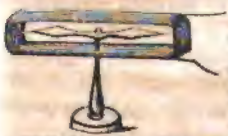
Simple as is the relation between the electric current on a wire, and the order of polarity induced by it in a needle, its correct expression is always difficult. To aid its correct statement by some simple formula, Ampère lays down the following rule.

That the north pole of a magnet is invariably deflected to the left of the current which passes between the needle and the observer, who is to have his face towards the needle, the electric current being supposed to enter from his feet, and pass out of his head.

A verification of these cardinal principles by actual experiment is the only way in which the student can obtain a vivid and lasting impression of them.

1011. **Galvanometers or multipliers.**—If the conjunctive wire is bent into a rectangle, fig. 626, so as to carry the current once or many times around the needle, then the effect of the same force on the needle is multiplied in proportion to the number of convolutions. Thus Schweigger contrived his *multiplier*, fig. 626, composed of a flat spool of fine insulated copper wire within which the needle was suspended. By this means a very feeble current became quite sensible. For ordinary purposes, a few turns, or it may be three hundred or four hundred

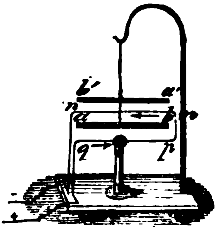
626



Explain the right angled influence by reference to fig. 625. How did Ampère state the order of polarity? 1011. What is Schweigger's multiplier?

convolutions suffice; but for particular purposes, and where the current is very feeble, many thousand feet of very fine wire are used.

627



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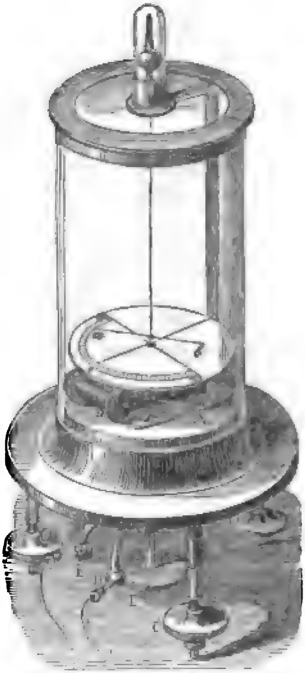

In *Nobili's double galvanometer* an astatic needle (882,) is used, in which the needles *a b*, *b' a'*, fig. 627, are not quite equal, leaving a very slight directive force only. Fig. 628 shows this delicate instrument in its most perfect form, as used in determining the laws of transmission of heat, (584,) as well as for other purposes demanding a very sensitive instrument. Only the lower and stronger needle is inclosed in the helix, *D*, while the system is suspended by a fibre of raw silk, beneath a glass shade, leveled by three screw feet, *C*. The ends of the spool are seen at *R H*, while by the head, *F*, the whole instrument may be revolved so as to bring the wires of the spool parallel to the suspended needle at rest, which is the position of greatest sensitiveness. The sensitiveness of such an arrangement is very great. Suppose, for example, there are five hundred revolutions in the coil, then the lower needle is acted on one thousand times, and the upper one five hundred times by any given current; or the original force of the current is multiplied fifteen hundred times. But the directing force of the earth's magnetism on a given needle is proportional to the squares of the vibrations it makes, (890.) Now, assuming that the needles alone made sixty vibrations in a minute, and as astatic needles only ten, then we have 3600 : 100 as the numbers representing the effect of terrestrial magnetism in the two cases; or it is thirty-six times less in the astatic system than in the simple

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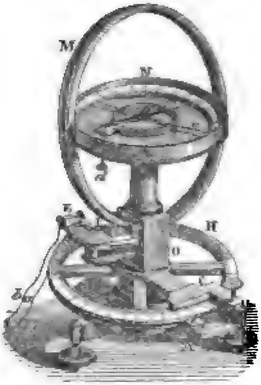
Describe Nobili's galvanometer. How is the sensitiveness of it illustrated? How much is the deflecting power of the current increased?

needles, and consequently, the electric current will affect them thirty-six times more than if they were not astatic. The deflecting power of the current in question will therefore be increased by such a galvanometer, 1500 × 36 = 54,000 times.

1012. **The tangents or sine compass, or galvanometer.**—This instrument, invented by M. Pouillet, is designed to measure currents of greater intensity than can be measured by the common galvanometer. It depends on the established principle, that the intensity of a current is proportional to the sine of the angular deviation of the needle. The angle of deviation being known, and consequently its sine, the intensity of the current is expressed in terms of the sine.

Fig. 629 shows the arrangement of this instrument, in which the current, entering by the conductors, *b a*, through the ivory piece, *E*, circulates a few times only, sometimes only once, over the vertical circle, *M*, placed in the magnetic meridian. The negative needle, *m*, is deflected upon the horizontal circle, *n*, in proportion to the force of the current in *n*, and a silver index needle, *n*, serves to record the angular deviation of *m* from its neutral point. When the needle is at rest, the vertical circle, *m*, is revolved upon the standard, *O*, by the button, *A*, until its plane coincides with the plane of deviation of *m*, and this angular distance is then read off by the vernier, *C*, upon the lower graduated circle, *H*. This galvanometer, or a simpler modification of it, is the form of instrument generally used in electro-magnetic researches.

629



1013. **Rheostat.**—This simple contrivance of Wheatstone's serves to introduce a longer or shorter conducting wire into any circuit, the intensity of which it is proposed to measure by the galvanometer.

Since the intensity of the current is inversely as the length of the circuit, (988,) we may, by increasing or diminishing that length, produce from any current a determinate deviation, (say 30°,) on the galvanometer. Fig. 630 shows this arrangement, composed of two equal and parallel cylinders, one of wood, *B*, and the other of brass, *A*, supported in a frame-work and revolving on their centres. *B* is

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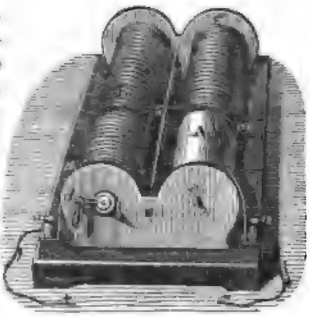
1012. What is the object of the line compass? Describe it. 1013. What is the rheostat?

provided with a spiral groove, in which the turns of a copper conducting wire may be laid. One end of this wire is at *s*, in connection with the current pole, *o*. The wire may all be wound on *B*, in which case the current passes through its whole length and escapes at *n*, through the metallic connection of its end, *e*, with *A*. If it is desired to shorten the conductor, the handle, *d*, is put on the axis, *c*, and *A* is revolved from left to right, until, as in the cut, one-half, for example, of the conductor is wound on *A*. But *A* being a metallic conductor, the current passes to *n* by the shortest course, and the only part of the wire in action is what remains wound on *B*, and this quantity is read off by an index and graduation engraved on the farther ends of the cylinders. This apparatus is indispensable in exact observations.

630



1014. **Ampere's electro-magnetic discoveries and theory.**—Immediately after the first announcement of Œrsted's discovery of the magnetic powers of a conjuctive wire, Ampère, one of the most renowned of the French physicists, (born 1755—died 1836,) commenced a series of experiments, (Sept. 1820,) to determine the laws concerned in these curious phenomena. Of three principal hypotheses which he framed to this end, he finally accepted and demonstrated the following, viz:

That a magnet is composed of independent elements or molecules, which act as if a closed electric circuit existed within each of them: in other words, each of these magnetic molecules may be replaced by a conjunctive wire bent on itself, in which a constant current of electricity is maintained, as from a voltaic circuit.

This hypothesis he maintained by singularly ingenious experiments, many of which were the direct suggestion of the hypothesis itself, and he brought all, by his power of mathematical analysis, into exact conformity with his theory. This theory recognizes only

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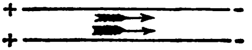
Describe its use. 1014. What is said of Ampère? What is the hypothesis he proved respecting electro-magnetism? How did he maintain it? What forces does it assume? How does it view magnets? What corollary follows?

such forces as are common to mechanical physics, and often called push and pull forces. These forces are mutual, and belong to all electric currents. In permanent magnets, the minute circular and parallel currents, pertaining, by this theory, to each magnetic molecule, all act at right angles to the magnetic axis or line of force. Hence, as in Œrsted's experiment, (1009,) the magnetic needle strives to place itself at right angles to the path of the current on the conjuctive wire, it follows, that currents in the magnet seek a parallelism to that in the conjuctive wire. Granting this to be true, it follows as a corollary from the premises,—

1st, that two free conducting wires must attract or repel each other, according to the direction of the currents in them. 2d, that a conjunctive wire may be made in all respects to simulate a magnet.

1015. **Mutual action of electric currents.**—*Parallel currents attract each other when they flow in the same direction*, as in fig. 631, where the arrows and the signs + and — indicate the flow of the currents to be identical, while in fig. 632, the same signs show the currents to be reversed, in conformity to the law that *parallel currents repel each other when their directions are opposite.* To illustrate these laws experimentally, one of the conductors should be fixed, and the other movable. (See the apparatus in Davis's Manual of Magnetism, fig. 159.) The following simple apparatus also illustrates these laws, and several other points of interest presently to be noticed.

631



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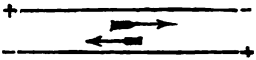
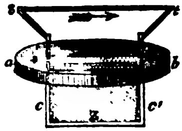


De La Rive's floating current, fig. 633, is a little battery of amalgamated zinc, *z*, and copper, *c*, or zinc and platinum, set afloat by a disc of cork, *a b*, whose poles + and — are connected by a conjunctive wire, *s t*. When this little float is placed in a vessel of acidulated water, (water with one-twentieth sulphuric acid,) an electric current flows in the direction of the arrow. Then join the poles of a single cell of Grove's or Smees' battery by a conjunctive wire of convenient length, and stretching the wire between the two hands, approach it parallel to *s t;* if the current is flowing in the same direction, the float will be attracted to the wire in the hands; if otherwise, repulsion is seen. If the two wires are not parallel to each other, then the movable current seeks to take up a

633

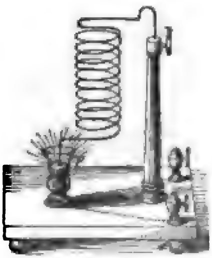


1016. What are the laws of parallel currents? How does De La Rive's floating current illustrate this? Describe it.

position of parallelism, or one in which the two currents have a similar direction. A little rectangular frame of wood 3" × 6", may be wound with ten or twelve turns of fine copper wire, covered by silk in the manner of a galvanometer, and its free ends connected with a battery will give a stronger current, and by simply turning the frame in the hand, the direction of the current is reversed.

ROGET'S OSCILLATING SPIRAL, fig. 634, also illustrates the law of attraction of parallel conductors. Here the conductor is coiled into a spiral, which is suspended from the top of an upright metallic standard in connection with one pole of a battery, while the other end dips into mercury in the glass, in connection with the other pole, *K*. When the poles are joined, each turn of the spiral attracts the next turn, shortening the spiral, and breaking the connection with a spark. The weight of the spiral then restores the connection, and thus a continuous oscillating movement is kept up.

634



1016. We add the following general propositions on this subject.

a. Two currents following each other in the same direction, as also different parts of the same current, repel each other.

b. Two fixed currents of equal intensity, flowing near and parallel to each other in opposite directions, (as when the same wire returns on itself without contact,) exert no influence on a fixed current running near them: in other words, they exactly neutralize each other, and their effect is *nil.*

The rotation of electric conductors about magnets, and the reverse; the rotation of a magnet on its own axis by an electric current, and the rotation of electrical conductors about each other, are all points most curious and instructive to trace, did space permit. The student will find these principles very neatly illustrated by appropriate apparatus in Davis' Manual of Magnetism. This is a most beautiful department of experimental physics, and one to which the researches of Henry, Page, and other American physicicists, have made very important additions.

1017. **Helix, solenoid, or electro-dynamic spiral.**—By winding the conjunctive wire into a helix, as in fig. 635, and carrying the wire back again through the axis of this spiral, *O B*, the effects of the current from *A* to *B*, will be neutralized by its re-

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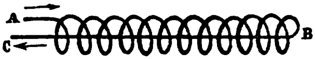
How does Roget's spiral illustrate these laws? 1016. What two general propositions are added?

turn from *B* to *C*, and there will remain only the effect due to its spiral revolution about *C B*. Ampère called this form of the wire a solenoid. The effect of the helix thus wound, is reduced solely to the influence of a series of equal and parallel circular currents. By winding the silk covered wire in the manner shown in fig. 636, the two ends of the coil are returned to the center of gravity, and being pointed with steel, the whole system can be conveniently suspended, as in fig. 637, upon what is called an Ampère's frame, in which the arrows show the course of the current from the battery thus suspended; the axis of the solenoid, *A B*, swings into the magnetic meridian, while its several spires are in the plane of the magnetic equator. This position it assumes in obedience to the solicitation of terrestrial magnetism; consequently it simulates in all respects the character of a magnetic needle, although possessing not a particle of iron or steel in its structure. If a second helix, *b*, through which also a current passes, is presented to the first, as in fig. 637, all the phenomena of attraction and repulsion will be seen, the action of the two helices or solenoids being to each other exactly like those of two magnets.

635



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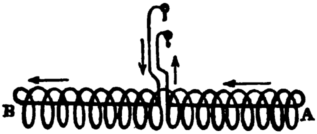

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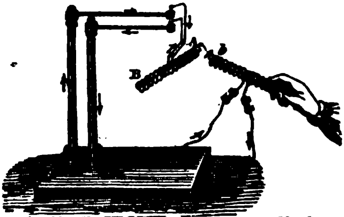
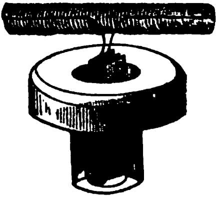


1018. **De La Rive's floating current,** already explained in section 1015, is also well adapted to illustrate the attractive and repulsive influence of a magnet on a free conjunctive wire, as well also as its obedience to the solicitations of terrestrial magnetism. For this purpose the conjunctive wire is wound, as in fig. 638, into a helix. Left to itself, this apparatus will act just

638



1017. What results if the wire is wound as in fig. 635? What is such an apparatus called? If wound as in fig. 636, how does it act in fig. 637? How is it affected by a second helix? 1018. How does fig. 638 illustrate these principles?

as the selenoid on the frame, fig. 637, and will obey the impulses of a magnetic bar, or of another solenoid.

1019. **Directive-action of the earth.**—These effects are expressed in the following law:

Terrestrial magnetism acts upon electric currents just as if the entire globe was encircled with electric currents from E. to W. in lines parallel to the magnetic equator.

The direction in which these currents are supposed to move is the same with the apparent motion of the sun, and the one in which the earth's surface receives its advancing rays; and since it is now known that electrical currents generated by heat exert precisely the same influence on the magnetic needle as Voltaic currents do, therefore it has been inferred that the thermal action of the sun is the generating and maintaining cause of the currents of terrestrial magnetism. (896.)

1020. **Magnetizing by the helix.**—We have already (901) described a mode of producing magnets from an electrical current. The explanation of this, after all that has been said, is easy. As each volute of the helix, causing an electric current, is an active magnet, it is easy to conceive that under the united influence of a great number of such circular and parallel currents, the coercive force of a steel bar, or bar of soft iron, should be decomposed, and active magnetism be thus induced, permanent or transient, according as steel or iron is the subject of experiment. Even a series of sparks from an excited electrical machine, passed through a helix, will magnetize a steel needle.

The position of the poles in a bar so situated will depend on the right-handed or left-handed twist of the spire. If the current flows from + to —, and the wire, as in fig. 639, turns from left to right, (like the hands of a watch,) then the north pole of the magnet is toward the left; but if the spire turns, as in fig. 640, from right to left, or opposite to the hands of a watch, then the poles are

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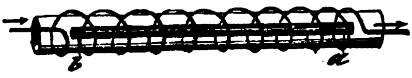
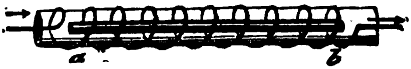




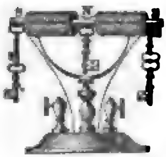
640

1019. What is the law of the earth's action on electric currents? What is the direction of the terrestrial currents? What general conclusion follows? 1020. Explain the magnetizing power of the helix. What determines the position of the poles in a helix?

reversed. "Let a person," observes Faraday, "imagine that he is looking down upon the dipping needle, or north magnetic pole of the earth, and then let him think upon the direction of the motion of the hand of a watch, or of a screw moving direct; currents in that direction would create such a magnet as the dipping needle."

If the helix is wound on a tube of glass, paper, or wood, these substances offer no resistance to the passage of the power; but if a tube of copper or lead were employed, the magnetizing power of the current on the inclosed bar would be destroyed.

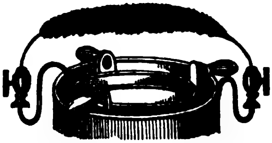
641



If the same helix is wound in two opposite directions, as in fig 641, then, according to the direction curent, there will be a pair of north poles at the point of reversal in the centre, (or a pair of south ones,) and the two ends will have the same name. A bar of steel placed in such a helix will remain permanently an anomalous magnet, (874.) Reversing the position of the bar in the helix, or reversing the position of the electrodes in the binding cups, will reverse its polarity.

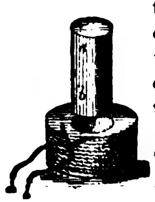
Arago's original experiment.—If a short conjunctive wire of copper, or any non-conducting metal, is strewn with iron filings, they will arrange themselves as seen in fig. 642, not bristling as in the magnetic phantom, with opposite polarities, (872,) but in close concentric rings, disposed over the whole length of the conductor. This fact was observed by Arago, in 1824, and by others, before the application of the helix to the induction of magnetism in soft iron.

642



When the helix is closely wound with many turns of insulated wire, and excited by a battery of considerable quantity, a cylinder of soft iron, as *a b*, in fig. 643, will be drawn into it from the position seen in the figure, with great power, and after several oscillations, will come to rest in the middle of its length, in opposition to gravity, realizing the fable of Mahomet's coffin, suspended in mid air without visible support. This fact is embraced in Dr. Page's electro-magnetic engine, fig 664.

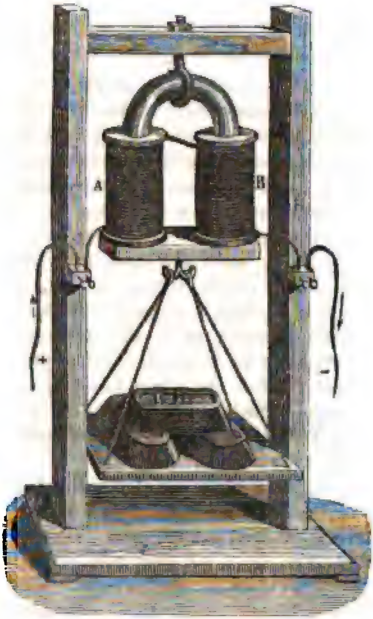
643



1021. **Electro-magnets.**—Sturgeon, of England, in 1825, appears to have been the first to produce soft iron electro-magnets.

How does Faraday illustrate the cause of the current? How is it if the helix is wound, as in fig. 641? What was Arago's experiment? How does the helix affect an iron bar?

644



Prof. Henry, and Dr. Ten Eyck, in 1830, produced electro-magnets of enormous power by a new mode of winding the inducing coil. (Sill. Jour, [1] xix, 400.) Electro-magnets are wound with coils of closely packed and insulated copper wire, varying in size and length, according to the use to be made of them; fig. 644, shows the usual form of those designed to sustain great weights. The spools at *B*, are virtually continuations of one spool, and the direction of the whorl is apparently reversed by the bend of the horse-shoe. If a lever of the third order (198) is used as a steelyard, the lumber of heavy weights is avoided, and the power of the apparatus easily tested. Prof. Henry, on a bar of fifty-nine lbs. weight, used twenty-six coils of wire, thirteen on each leg, all joined to a common conductor by their opposite ends, and having an aggregate length of seven hundred and twenty-eight feet. This apparatus, with a battery of four and seven-ninths feet of surface, sustained two thousand and sixty-three pounds avoirdupois: with a little larger battery surface it sustained twenty-five hundred lbs. Electro-magnets develop their surprising power only when the armature is in contact with the poles, a fact due to induction; without their armatures, they sustain not a tenth part of their maximum load. They are capable of over saturation by an excess of battery power, and retain a remarkable residual force

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1021. Who made the first electro-magnets? How are these wound? What is said of Henry's? When is their power developed? What of their polarity? What circumstances affect their power? What laws has Dub established?

(due to induction) after that has been cut off, so long as the keeper is in place, but as soon as the armature is detached, the whole of this magnetism is lost. Their polarity is instantaneously reversed by reversing the poles of the battery. This complete and immediate paralysis and reversal of power, renders these magnets of inestimable value in dynamical electricity.

The chief circumstances affecting the production of electro-magnets are, 1st, the quality of the iron, which should be the softest and purest possible, and the bar, if bent and hammered, should afterwards be most carefully annealed for a long time. 2d, the form of the bar. Dub has shown, that other things being equal, the power of an electro-magnet is proportional to the square root of the diameter of the cylinder, and consequently for magnets destined to lift great weights, short and thick cylinders are preferable. 3d, with a given battery power, Henry, (*loc. cit.*) demonstrated that a series of short coils of thick wire produced the greatest effect. But in case of feeble currents, as in the electro-magnetic telegraph, long and fine copper wire produces, on the principle of the galvanometer, the best results; the effect being as the square of the number of windings. The latest researches on this most important subject are by Dr. Dub, abstracts of whose results can be seen in Silliman's Journal, (2) vol xvii, 424.

Dr. Page, in his experiments on electro-magnetism as a moving power, constructed coils which raised cylinders of iron weighing over six hundred pounds each. On the poles of a horse-shoe magnet, with an armature, such coils could lift an incredible weight.

1022. **Vibrations and musical tones from indued magnetism.** Dr. Page, in 1837, noticed the production of a musical sound from a magnet, between the poles of which a flat spiral was placed. The sound was heard whenever contact was made or broken between the coil and the battery. Two notes were distinguished, one the proper musical tone of the magnet, and the other an octave higher. De La Rive, Delezenne, and others, have confirmed and extended these curious observations. The existence of molecular disturbance in receiving and parting with magnetic induction, has been farther illustrated by the same ingenious observer, by the vibrations imparted to Trevellyan's bars by the current from two or three cells of Grove's battery. (Sill. Jour. [2] ix, 105.) Trevellyan's bars are prismatic bars of brass, hollow on one side, so as to rest by sharp edges on blocks of lead. When these are gently warmed, and then laid upon the leaden blocks, the unequal expansion and contraction of the

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1022. What is said of the vibrations of magnets? What other example of electro magnetic vibrations is given?

two metals, gives the brass bars a slight motion of vibration, due to molecular disturbance by heat. A voltaic current, according to Dr. Page's observation, produces the same effect as heat, but more remarkably.

1028. **Electro-magnetic motions and mechanical power.**—The facility with which masses of soft iron may be endued with enormous magnetic power by currents of Voltaic electricity, and again discharged, or reversed in polarity, has led to numberless contrivances to use this power as a mechanical agent. A great variety of pleasing and instructive models of such machines, with the use both of permanent magnets and of electro-magnetic armatures, or of electro-magnets only, are described in Davis's Manual of Magnetism.

We annex a figure of an electro-magnetic engine, contrived by Dr. Page, similar to one by which he obtained a useful effect of ten horse-power, in driving machinery and transporting a railway train. *A* and *B*, fig. 645, are two very powerful helices of insulated copper wire, within which are two heavy cylinders of soft iron, *C D*, counter-balanced on the ends of a beam, *G F I*, like the working beam of a steam engine. By the movement of an eccentric, *L*, on the main shaft of the fly wheel, the poles are changed, at the moment, to magnetize and de-magnetize, alternately, the two helices, drawing into them the two soft iron cylinders, by a force of many hundred pounds. Prof. W. R. Johnson tested the force of an engine of this kind built by Dr. Page

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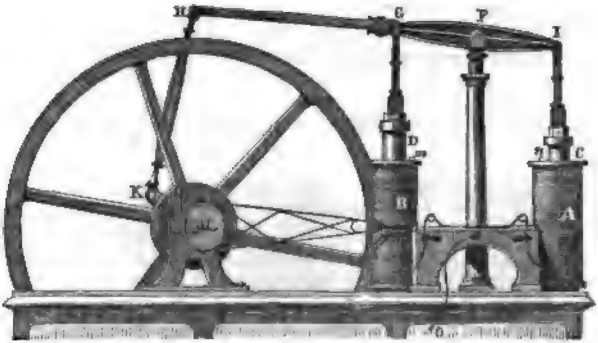

1028. What is said of the adaptation of electro-magnets to mechanical power? Describe Dr. Page's electro-magnetic engine, fig. 645.

in 1850, and found it to give about six and a half horse power. (Sill. Jour. [2] x, 472.)

M. Jacobi, of St. Petersburg, has studied this subject very carefully, and has contrived an effective form of rotating machine, very similar to that of Cook and Davenport, so well known in the U. S. in 1837. Froment, of Paris, has also constructed a powerful apparatus of this sort, in which armatures of soft iron on the periphery of a wheel are drawn towards electro-magnets placed radially.

In all these machines it is heat developed by chemical action that is transformed, in the form of magnetic-attraction, into mechanical work. (707.) As the result of a great many experiments, Mr. Joule has shown that the best theoretical result from the heat, equivalent to the solution of a grain of zinc in a battery, is eighty lbs. raised one foot high. But a grain of coal burned in a Cornish boiler, raises one hundred and forty-three lbs. one foot, and the price of the coal is to that of the zinc as 9d per cwt., to 216d per cwt. Therefore, under the best conditions, (which are never reached in practice,) the magnetic force is 25 times dearer than that of steam. Until, therefore, zinc is cheaper than coal, in the proportion of 80 to 143, coal will probably be burned in atmospheric air, preferably to the combustion of zinc in sulphuric acid, to produce mechanical work.

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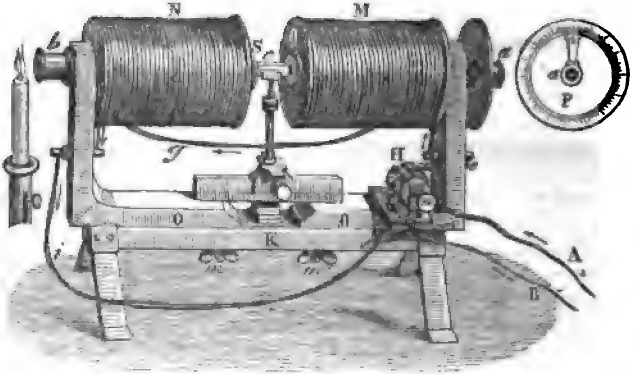

1024. **Action of magnetism on light.**—Fig. 646 shows the apparatus designed by Ruhmkorff, in illustration of Faraday's magnetic rotatory polarization of light already spoken of under Optics,

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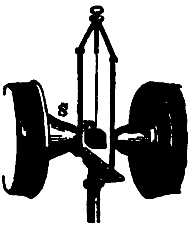
What is said of the mechanical equivalents of electro-magnetism?

(865.) Two powerful inducing coils, *N* and *M*, surround two hollow cylinders of soft iron, *S* and *Q*. The current enters the bobbins by *A*, and following the direction of the arrows, returns by *B*. The two coils slide in the groove in the base, *K*, on the two supports, *O O*, so that they may be approached or withdrawn at pleasure by turning the screws *m m*. A commutator, or interruptor of the current, is arranged at *H n*. At *a* and *b* are two Nicol's prisms, (859,) of which *a* has a vernier or index, reading the degrees on the graduated circle, *P*. To make the experiment, a piece of heavy glass, *c*, or silicious-borate of lead is placed on a support between the poles *S* and *Q*. A ray of polarized light is then transmitted from the candle at *b*, through the glass in the axis of the poles. When the current is applied, the ray of light appears to be revolved, similarly to the effect produced on polarised light by quartz, or oil of turpentine. A great number of other solids and liquids are found to act in a like manner, but to a less degree, than in the case of 'heavy glass.' As no rotation of the ray takes place unless there is *some medium* on which the magnetism may act, it has been argued with some force by M. Becquerel and others, that the action is wholly due to a molecular change in the solid under experiment. A reversal however of the direction in which the ray travels, reverses the direction of rotation in the polarized ray, a circumstance not found in bodies in the natural state. This apparatus also serves to illustrate the phenomena of diamagnetism.

1025. **Diamagnetism.**—We have already, (894,) alluded to the action of magnetism upon all bodies, discovered by Dr. Faraday, in 1846, a discovery which alone would place its author in the highest rank of modern philosophers. By the use of the apparatus, fig. 646, he proved that every substance which he tried, solid, fluid, or gaseous, was subject to magnetic influence, assuming either the *equatorial* or *axial* position, according to its nature. (804.)

647



For solids, and some fluids, fig. 648 shows the arrangement. Two bluntly rounded polar pieces of soft iron are fitted into the openings of the spools, *S* and *Q*, while between them are suspended on a silk fiber cubes, *m*, or short bars of the various mag-

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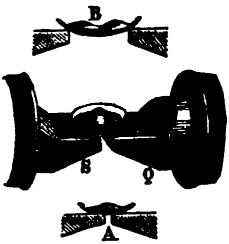
1024. What is the purpose of fig. 646? Describe the action of this apparatus? 1025. What is said of diamagnetism? Describe the experiments made with figs. 647, 648.

netic metals, bismuth, antimony, copper, lead, tin, &c. If the cube is spinning about when the current passes, the indued magnetism arrests its motion in whatever position it may be, and if the metal has the form of a little bar, it rests athwart the axis like a cross. If non-magnetic liquids, alcohol, water, and most saline solutions are confined in little narrow bottles, (like homeopathic vials,) hung, like *m*, figs. 647, these are similarly affected. If they are filled, however, with magnetic solutions, the salts of iron, nickel, or cobalt, they then arrange themselves axially.

648



Plücker has shown that if these magnetic solutions are placed in watch glasses upon the poles, *S Q*, as in fig. 648, that according as the poles are nearer or farther asunder, these liquids are heaped up in one or two elevations, as in *A* and *B*.

The flame of a candle placed between the poles, *S Q*, fig. 649, is strongly repelled, a fact first observed by Father Bancalari, of Genoa, and the flames of combustible gas from various sources are differently affected, both by the nature of the combustible and by the nearness of the poles. The flame from turpentine is most curiously affected, being thrown into the form of a parabola, whose two arms stretch upward a great distance, and are each crowned by a spiral of smoke. Oxygen, which in the air is powerfully magnetic, (895,) becomes when heated diamagnetic. A coil of platinum wire heated by a current of Voltaic electricity and placed beneath the poles of Faraday's apparatus, 647, occasions a powerful upward current of air, but when magnetism is induced, the ascending current divides, and a descending current flows down between the upward currents. The following list expresses the order of some of the most common *paramagnetic* substances, viz: Iron, nickel, cobalt, manganese, palladium, crown-glass, platinum, osmium. The zero is *vacuum*. The *diamagnetics* are arranged in the inverse order, commencing with the most neutral; arsenic, ether, alcohol, gold, water, mercury, flint-glass, tin, "heavy glass," antimony, phosphorus, bismuth.

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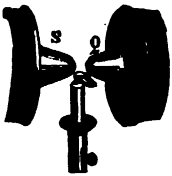

Plücker has farther demonstrated the important fact that the optic axis of Iceland spar is repelled by the magnet, a fact probably true of many crystals—in some of which the magnetic axis is parallel to the longer axis of crystallization. Thus a piece of kyonite will,

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What is the action on gas flames? What on that of turpentine? Give a list of paramagnetic and diamagnetic substances.

under the influence even of the earth's magnetism, arrange itself like a magnetic needle.

ELECTRIC TELEGRAPH.

1026. **Historical.**—The thought of making telegraphic communications by electricity appears to have suggested itself as soon as it was known that an electrical current passed over a conducting wire without sensible loss of time. The following brief summary of well-known historical facts, will serve at once to show how impossible it is justly to bestow the exclusive merit of the electric telegraph upon any inventor, while at the same time it strikingly illustrates what is true of every important invention, that final success rescues from oblivion many schemes that had hardly vitality enough in their day to find a place in the records of history.

In 1747, Dr. J. WATSON, erected a telegraph from the rooms of the Royal Society, in London, for two miles or more, over the chimney tops, using frictional electricity on a single wire, with the earth for a return circuit. (*Phil. Trans.* xiv, 1848.) In 1748, Dr. FRANKLIN set fire to spirits of wine by a current of electricity sent across the Schuylkill on a wire, and returning by the river and the earth. In 1774, LE SAGE, a Frenchman, established at Geneva an electric telegraph, in which he used twenty-four wires insulated in glass tubes buried in the earth, each wire communicating with an electroscope, and corresponding to a letter of the alphabet, and excited by an electrical machine. (MOIGNO *Traité*, 59.) In 1787, BETANCOURT, in Spain, made an effort to employ electricity for telegraphing by passing signals from a Leyden vial over wires connecting Madrid with Aranjuez, a distance of twenty-six miles. SALVA, in 1796, also presented to the Academy of Madrid, a plan of an electric telegraph of his own invention, which received the patronage of the Prince of Peace. In 1800, the public announcement (966, 967,) of VOLTA's discovery, of the pile, supplied a new means for telegraphing, far more certain than frictional electricity, and accordingly we find, that in 1811, Prof. SOEMMERING, of Munich, proposed to the academy a complete plan, with details, for an *electro-chemical* telegraph, in which he used thirty-five wires, (twenty-five for the German alphabet, and ten for the numerals,) tipped with gold and covered by the same number of glass tubes filled with water, to be decomposed whenever the

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1026. What suggested the electric telegraph? Rehearse the history given. What discovery in 1800 made electric telegraphs practicable? What was Soemmering's plan?

corresponding letter or numeral was touched by the battery wire on a key-board at the other end. This is the type of all electro-chemical telegraphs. Dr. J. REDMAN COXE, of Philadelphia, in 1816, in Thompson's Annals of Philosophy, apparently without knowledge of Soemmering's plan, proposes a similar one by the use of galvanic electricity. In 1819–20, ŒRSTED's discovery of electro-magnetism, and AMPERE's development of the subject, opened the way to electro-magnetic telegraphy. Œrsted first, and then Ampère, proposed the plan of a telegraph, using the deflections of a magnetic needle for signals; the type of Wheatstone's needle telegraph; but their suggestions were never put in practice. In 1823, Dr. F. RONALD's, of England, published a volume detailing the plan upon which he had previously constructed eight miles of electric telegraph, and in which he used a movable disc, carrying the letters, the type of all dial telegraphs. In 1825, WILLIAM STURGEON, of Woolwich, Eng., made the first electro-magnet of soft iron, without which, further progress in the electro-magnetic telegraph was impossible. Prof. JOSEPH HENRY, in 1830, first described a mode of giving much greater power to electro-magnets, and the same philosopher, in 1831, described the first reciprocating electro-magnet and vibrating armature, including also the principle of the relay magnet, so indispensable an auxiliary in the Morse system. (Sill. Jour. [1] xx, 340.) In 1834, Messrs. WEBBER and GAUSS, established an electro-magnetic telegraph at Gottengen, between the Observatory and the Physical Cabinet of the university, and used it for all the purposes of scientific communication.

In 1836, Prof. J. F. DANIELL invented the constant battery, (976,) without which any mode of electric telegraph would have been futile.

In 1837—ever memorable in telegraphic history for the first general and successful introduction of the electro-magnetic telegraph—and almost at the same time appeared MORSE, in the U. S.; STEINHEIL, at Munich, and WHEATSTONE and COOKE, in Eng., as distinct and independent claimants for the honor of this discovery. Prof. J. D. Forbes, the able historian of the Physical Sciences, in the eighth edition of the Encyc. Brit., speaking of these inventions, says: 'the telegraph of the two last, (Steinheil and Wheatstone,) resembles in principle Œrsted's and Gauss's: that of the first, (MORSE,) is entirely original, and consist in making a ribbon of paper move by clock-work, whilst interrupted marks are impressed upon it by a pen,' &c. * * 'The telegraphs of Morse have the inestimable advantage,

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What was it in 1820 put a new face on this subject? What did Sturgeon do? What is said of Daniell's battery? What of the year 1837?

that they preserve a permanent record of the despatches which they convey.' This advantage, it is but just to say, they share with Bain's electro-chemical telegraph.

1027. **The earth circuit.**—Although Drs. Watson and Franklin, (1747-8,) used the earth as the return circuit in their telegraphic experiments, it was considered essential in the use of Voltaic electricity to employ at least two wires, until Steinheil, in 1837, in the construction of his telegraph at Munich, dispensed with the whole resistance of the return wire by burying a large plate of copper at each station, with which the circuit wire communicated. This certainly must be esteemed one of the finest discoveries in connection with the telegraph; but from some cause or other it obtained for some years but little publicity, although described at length in the *Comptes-Rendus*, of Sept. 10, 1838. Bain re-discovered the same fact some years later, and Matteucci, of Pisa, in 1843, made experiments which convinced the most incredulous of the truth of this important fact.

Fig. 650, illustrates the mode of using the earth circuit, now universal in all telegraphs. *S* and *S'*, are two distant stations, with their batteries, *b b'*, and magnets *m m'*, a wire passing over insulating posts, through the air, connects *S* and *S'*. One pole of each battery is connected with the earth through the magnets, ending in plates of copper, *P P'*. Neither battery will, however, act, unless one of the breaks, or finger keys, *S* or *S'*, is depressed. If the finger-key, *S*, is depressed, the circuit consequently is completed *through the earth*, for the battery, *b*, while that of *b'* remains open. The

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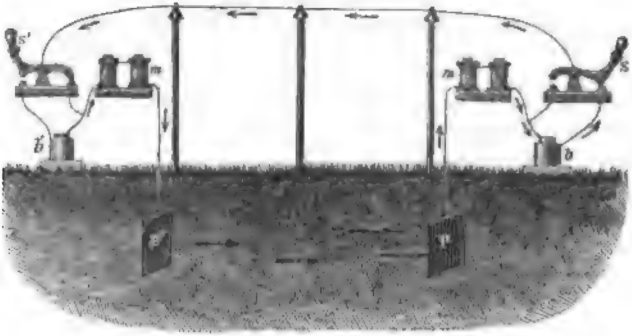

1027. Explain the earth circuit. Who discovered and who re-discovered it? Explain it from fig. 650.

arrows show the course of the current, and this will be reversed when the circuit at S is closed. The explanation of this curious fact appears to be, not that the electricity is conducted back by the earth to its origin at the battery, but that the molecular disturbance in which the polarity of the circuit consists, is effectually relieved by communication with the common reservoir of neutral electricity, (911,) and so conduction proceeds without interruption. Any number of parallel currents may thus co-exist without interference. This simple device saves not only half the expense of constructing lines, but it more than doubles their power of electrical transmission. For the rapidity of the current, refer to section 917.

1028. **Varieties of electro-telegraphic communication.**—There are essentially but two modes of electro-telegraphic communication, viz: the *electro-mechanical* and the *electro-chemical*. Various and seemingly unlike as are the numerous ingenious contrivances for this purpose, they all fall under one of these two divisions.

The electro-mechanical form of telegraphic apparatus, embraces the *needle* telegraph, the *dial* telegraphs, and the *electro-magnetic*, or *recording* telegraphs: both those which, like Morse's, use a cypher, and those, like House's, which print in legible characters.

The electro-chemical telegraphs, (having their type in Soemmerings' original contrivance,) depend on the production of a visible and permanent effect, as the result of some chemical decomposition at the remote station; of these, Bain's is the best known.

This is not the place, had we space, to give all the details of the well-known machines in use for telegraphic purposes. A few words, stating the principles on which they all depend, with a notice of two or three of those most used in the U. S., must suffice.

As the needle telegraph of Messrs. Wheatstone and Cooke (depending on the deflection of a needle by a galvanometer *coil)* has never been used in this country, and cannot compete with either of the systems adopted here, it is needless to describe it. It requires one operator to read the movements of the needle, and another to record the message, and its average capacity is not over ten or twelve words per minute. The dial telegraph of Froment, and others, is open to the same objections.

1029. **Morse's recording telegraph.**—Every electro-telegraphic apparatus implies the use of at least two instruments, one for

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1028. How is electro-telegraphic communication classified? What examples are given of each class?

recording, and one for transmitting the message. Besides these, in most cases there is need of a *relay magnet*, which receives the circuit current and acts to bring into use the power of a local battery, by which the work of recording is performed. This is requisite because the circuit current is usually too feeble to do more than establish a communication with the local battery. Every recording instrument has a clock-work, or some similar mechanical movement, to carry forward the paper fillet on which the record is impressed, at a regular rate of motion. Fig. 651 shows the Morse recording instrument.

It consists, essentially, of a simple lever, A, with a soft iron armature, *E*, over the electro-magnets, *E F*, by which the electrical impulses are propagated to the pen or styto, *o*. A weight, *P*, gives motion to a train of wheels, *K C*, by which the fillet of paper, *p p*, is caried over the rollers, *G H*, in the direction of the arrows. A feeble spring, *r*, withdraws the point, *o*, and armature, *D*, when the electricity ceases, and the motion of the pen-lever is farther adjusted by two regulating screws, *m m*, that can be set at pleasure. The battery current enters the apparatus at the binding screws, *a b*.

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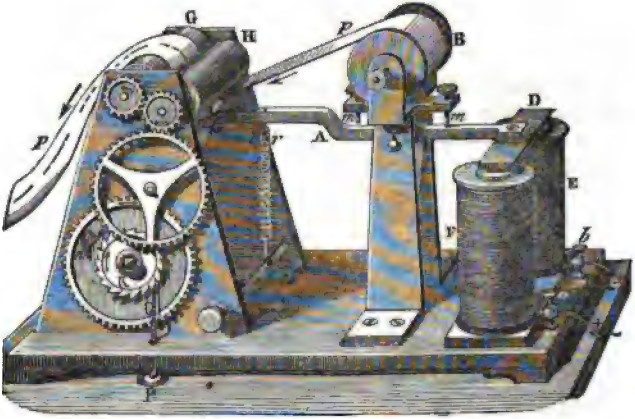

The message is recorded by a cypher of dots and dashes, made on the moving fillet by the point of the pen-lever. The lever moves in obedience to the impulses of the operator at the transmitting station, who presses the '*finger key*,' for a longer or shorter instant, ac-

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1029. What is essential in every electro-telegraphic system? Explain Morse's recording telegraph. What is the finger key?

cording to what he would transmit. Every motion of the pen lever gives a sound, corresponding to the letter communicated; and to a practiced operator, this sound becomes a definite language, which his ear interprets with unfailing certainty, so that he literally hears the message and translates it without the necessity of looking at the record. Fig. 652 shows the *spring finger key,* by which messages are transmitted. The Morse instrument has the advantage of great mechanical simplicity, so that it requires but little skill to manage it, and its record being permanent and sufficiently rapid for all ordinary purposes, it has become more generally used in the U. S. than any other, and over the continent of Europe has been very generally adopted. Mr. Morse conceived this plan of telegraphic transmission in 1833, but it was only in 1837 he applied for his first patent, and in 1844 the first line was built in the U. S., from Washington to Baltimore.

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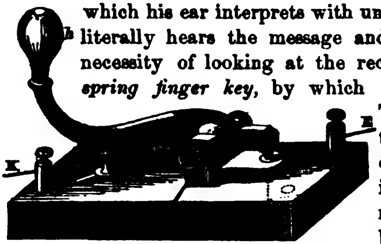

1030. **House's electro-printing telegraph.**—This most ingenious instrument records its message in plain printed characters, and as a mechanism, must be regarded as one of the most wonderful results of inventive genius. An imperfect drawing of its chief parts is seen in fig. 653.

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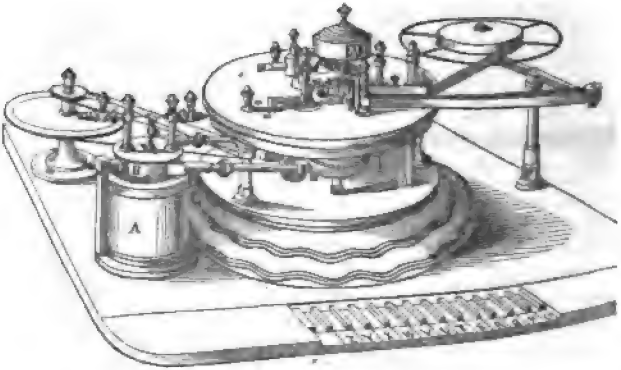

Its chief parts are a key-board, marked with the letters of the alphabet; a type wheel, *o*, on which the letters of the alphabet are engraved; a helical coil of fine wire in the cylinder, *A*, in connection

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1030. What is the nature and action of House's apparatus? 1031. What is the electro-chemical telegraph? Explain Bain's system.

with the circuit, and which operates to open a valve for the emission of a blast of air, compressed by a pump under the table into a receiver, *B*. The purpose of this blast is to work the escapement regulating the motions of the type wheel, *a*. This is the only function of the electricity in the machine for recording; every other motion is a mechanical one. The electricity, by opening and closing the air valve, regulates the motion of the type wheel, arresting it at the pleasure of the operator at the distant station, who, by touching on his key-board the letter he would transmit, arrests the type wheel of the recording instrument at that letter; a simple mechanism then presses the fillet of paper on the face of the type, and moves the paper forward to receive the next impression. Its actions are quicker than thought, and owing to the exact duality of the two machines in every part, and the perfect equality of their motion, the operator transmitting is as conscious as him receiving, if there is any error, aided as he is by a tell-tale above the type wheel, showing, in our design, the letter *A*. It is impossible, without many pages of detail and minute drawings of the parts, to render this marvel of mechanical art perfectly intelligible. But the general thought of the inventor is clear enough, to place the recording apparatus at the control of the transmitting operator, through the agency of compressed air, controlled by the electric current, and controlling in its turn the escapements of the recording apparatus. It prints about one hundred letters per minute, on a circuit of one hundred and fifty miles.

1031. **The electro-chemical telegraph,** depends on the decomposition by the electrical current of a salt of iron with which the paper fillet is saturated, and the production of a blue or red stain upon it. The same clock-work movement used by Morse, carries forward the paper over a metallic cylinder which is one pole of the circuit, while a steel pen (if a blue mark is intended, or copper, if red is intended) in connection with the other pole, bears steadily upon the paper; the least transit of electric force decomposes the prussiate of potassa with which the paper is charged, producing a stain. To insure the dampness in the fillet requisite for electrical conduction, Maison-Neuve has proposed to charge it with a solution of nitrate of ammonia, a salt whose attraction for moisture is such that the paper remains always damp. To avoid errors, as well as to insure greater rapidity, Bain, who was the author of this system, proposed to prepare the messages, or fillets of paper, punched with holes by a machine called a *compositor* or *multiplier*. Humaston has lately so improved the mechanism of this compositor that it is possible, by combining

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What is the multiplier? What is said of its rapidity?

this apparatus with the Bain system of reading, to transmit not less than three thousand signals per minute, equal to six hundred letters, or one hundred and twenty-five words of five letters each. The punched fillets take the place of the finger-key as a circuit breaker for the transmission of the message.

AUTOGRAPH TELEGRAPHIC MESSAGES can be transmitted by the electro-chemical method, by writing upon the transmitting cylinder, with solution of wax, and then causing a tracing point to traverse the cylinder with a close spiral from end to end. The result is, the interruption of the current where the wax is, and a corresponding blank space left on the paper at the receiving station. The union of these white spaces gives what was written in wax in a white character on a dark ground.

1032. **Submarine telegraphs—the Atlantic cable.**—The first submarine telegraphic cable was successfully sunk in August, 1851, connecting Dover, in Eng., with France, at cape Griz Nez. Since that time, numerous other submarine cables have been laid, of which that through the Black Sea was the longest, until the placing of the Atlantic cable was accomplished, on the 5th of August, 1858.

Fig. 654 shows the exact size and mode of construction of this cable. The conducting wire is formed of seven strands of No. 32 copper, twisted into a cord, and buried in refined gutta percha, laid on in three coatings, by machinery. The whole is encased in seventeen strands of iron wire, each strand formed of seven No. 30 iron wires. It weighs about two thousand lbs. to the nautical mile, and about two thousand miles of it lie submerged between Valentia bay, Ireland, and Trinity bay, Newfoundland. The shore end is formed of ten miles of much stronger cable, inclosing, however, the same conductor.

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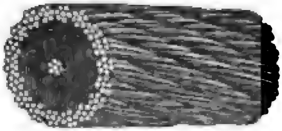

The problem of scientific as well as practical interest in the cable is the possibility of transmitting signals through it with sufficient rapidity for useful purposes. Faraday has shown that a gutta-percha covered wire is, when submerged in water, in very different electrical conditions from what it is in air. In the water it simulates the character of the electrical condenser, or Leyden vial, and when thus charged by induction, must be discharged before a second wave can be transmitted through it; and when the electric pulses are frequent,

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How may autograph messages be transmitted? 1032. What is said of submarine telegraphs? What of the Atlantic cable? What has Faraday shown on this subject?

as in telegraphic communications, the effect of the *electric conflict*, as Œrsted originally termed it, is to produce a tremor in place of sharp and decided beats. In the absence of any exact statements from the Electricians in charge of this great international nerve of sensation, we cannot do better than refer the student to Faraday's papers. (Ept. Res. vol. 3d, p. 507—523 and 575.)

1033. **Electrical clocks and astronomical records.**—If a clock pendulum is by any mechanical device made to open and close the circuit in a telegraphic arrangement, it is obvious that if the clock beats seconds, these will appear recorded as dots at equal intervals upon the paper fillet. An astronomer watching the transit of a star across the wires of his telescope, with his hand upon the finger-key of the same circuit, closes it at the exact instant of time, and the record of the passage of the star is fixed with unerring certainty between the beats of the clock and upon the same fillet which bears record of the time in seconds and their subdivisions. This beautiful system is wholly and peculiarly American, as the clear records of science show, and offers incomparably the best possible mode of determining longitude differences. The names of Bond, Gould, Locke, Mitchel, Saxton, Walker, Wilkes, and others, are inseparably connected with the history of this important application of the telegraph, for the details of which the student is referred to the Am. Jour. of Science, the proceedings of the Am. Assoc. for the advancement of Science, and the reports of the U. S. Coast Survey.

Bain, it is believed, constructed the first electrical clock (in 1842) which was moved by a current, from a large copper and zinc plate buried in the earth, or better, to a zinc plate buried in charcoal. By any simple mechanical arrangement, the motion of the pendulum reverses or breaks the current at every beat, and by the aid of a stationary magnet, the vibratory movement due to the electric current is strengthened and perpetuated. It is possible to transmit the same electric current to any number of clocks, in the same place, or in different places, and thus secure exact equality of time. The city of Boston is provided by a telegraphic system due to Dr. Channing and Mr. Farmer, by which a fire alarm is sounded in every ward: a detailed description of which will be found in Sill. Jour. [2] xiii, 58.

ELECTRO-DYNAMIC INDUCTION AND MAGNETO-ELECTRICITY.

1034. **Currents induced from other currents.**—The phenom-

1033. What of electrical clocks? How are they used in astronomy? Where did this system originate? Who made the first electrical clock?

ena of electro-magnetism seem to point as an almost necessary consequence to the discovery made by Faraday in 1831–2, of *induced currents*, and of *magneto-electricity*. Faraday argued thus.

1st. *That as a wire carrying a current acts like a magnet, therefore it ought by induction to excite a current in another wire near it.*

2d. *That as magnetism is induced by electric currents, so magnets ought also, under proper conditions, to excite electric currents.*

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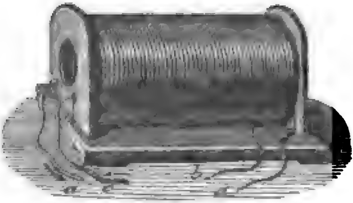

The first of these *theses* Faraday sustained thus: Let a double helix, or bobbin, be wound of two parallel silk covered wires, about a cylinder of wood, (which being withdrawn afterwards, leaves the helix hollow,) in close contact, but perfectly insulated, so that the two wires run side by side through the whole course. Let the ends, *b c*, fig. 655, of one wire be connected with a galvanometer, or magnetizing spiral, while a battery current enters the other wire by *c*, and passes out by *d*. When contact is made between *c* and the battery, the galvanometer needle is deflected by a current moving in the *same direction*, with the battery, or *primary* current, but only for a brief instant. After a few vibrations the needle comes to rest, although the battery current still flows. Break now the contact between the wire, *c*, and the battery, and the galvanometer needle is again deflected by a secondary or induced current; but this time it moves in the *opposite direction* to the first. These are called *secondary* or *induced* currents. They are *momentary*, but are renewed with every interruption of the battery circuit, and their strength is always exactly proportional to the strength of the primary or inducing current. If a mass of soft iron, (or better, a bundle of soft iron wires,) is placed in the core of the helix, the force of the induced currents is greatly increased. This action of a current from a Voltaic battery, Faraday called *Volta-electric induction.*

1084. To what do the phenomena of electro-magnetism point? How did Faraday demonstrate the induction of currents from currents? What is their strength and duration? To what are they analogous?

The phenomena of influence (927) in electricity present a strong analogy to these facts, and support the probability that the secondary currents, in the case of Voltaic induction, are also due to decomposition of the natural electricity of the second wire, by the current on the first. In fact, a current of statical electricity may be substituted for the Voltaic current with similar results, as was shown by Henry, in 1838, (Trans. Am. Phil. Soc., vol. 6. N. S.,) and (Sill. Jour. [1] xxxviii, 209.) Fig. 656, is a convenient form of apparatus designed by Matteucci, for this experiment. Two coils of insulated wire *A B*, are sustained on movable feet, admitting of near approach. When the charge of a Leyden jar, *D*, is passed through the coil *c d* on *A*, a person whose hands grasp the conductors, *i h*, of the coil, *B*, will receive a shock, the violence of which increases with the closer approach of *A* and *B*. The direction of the current in *B*, is the reverse of that in *A*. If a galvanometer is inserted in the circuit of *i h*, its needle is deflected, or if a magnetizing spiral is used, needles may be magnetized by it.

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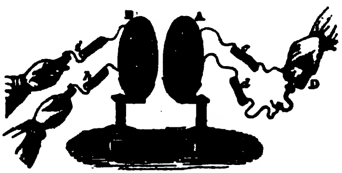

1035. **Henry's secondary currents of different orders.**—By using a series of flat spirals of copper ribbon, and of helices of insulated fine wire, alternately, Prof. Henry (*loc. cit.*) demonstrated, in 1838, that secondary, or induced currents, produced other induced currents of the second, third, fourth, and so on, to the ninth order, alternating with each other in the signs + and —, after the first remove from the battery current, and also alternating in the qualities of intensity and quantity, *i. e.*, he proved that a quantity current can be induced from one of intensity, and the converse.

1036. **Extra-current, or the induction of a current on itself.** The effect of a long and stout conductor in giving a vivid spark and shocks from a single cell, (which alone, or with a short conductor, gives neither sparks nor shocks,) was first noticed in 1832 by Prof. Henry. (Sill. Jour. [1] xxii, 404.) This fact was afterwards the subject of investigation by Faraday, in Dec. 1834, and also by Henry, in Jan. 1835. Faraday states his conclusion

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Who first showed this analogy, and how? 1035. What is said of secondary currents of different orders? 1036. What is the extra current? Who discovered it?

thus: "If a current be established in a wire, and another wire, forming a complete circuit, be placed parallel to the first, at the moment the current in the first is stopped, it induces a current in the *same* direction in the second, the first exhibiting then but a feeble spark; but if the second wire be away, disjunction of the first wire induces a current on itself in the same direction, producing a strong spark. The strong spark in the single long wire or helix, at the time of disjunction, is therefore the equivalent of the current which would be produced in a neighboring wire if such current were permitted." This effect is greatly enhanced by coiling the wire into a helix. In powerful coils, this extra-current produces sparks, which resemble the explosion of a pistol, especially under the inductive influence of a powerful electro-magnet, as in the engine of Dr. Page, already noticed, (1028,) the heavy coils of which produced sparks from the extra current from two to six inches in length, and having the same rotative action as the conductor itself. (Sill. Jour. [2] xi, 191.) Many forms of electro-magnetic apparatus, in which two coils are combined, show the extra-current in a striking manner, as in—

Page's vibrating armature and electrotome.—In this apparatus, fig. 657, the flow of the battery current is interrupted by the movements of the bent wire, *P W C*. At *M* is a bundle of soft iron wires, forming the core of the inducing coil: and becoming magnetic they attract a small mass of iron on the end of *P* to *M*. This raises the other end out of the mercury in the cup, *C*, with a brilliant spark, due to the flow of the extra-current, the magnetism having disappeared by the break of the battery flow. Gravity then restores the wire to its original position, thus renewing the current and the magnetism, and with it the spark in *C*. A fine wire induction coil of two thousand, or three thousand feet, wound about

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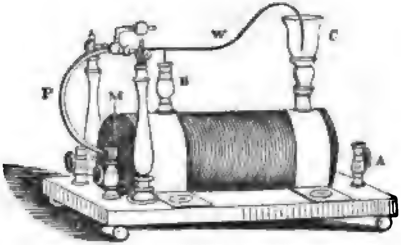

What is Faraday's view of it? What increases its force? Give an example. Describe Page's apparatus, fig. 657. What does it illustrate?

the inducing coil, develops the secondary currents already noticed, with powerful physiological and other inductive effects, resembling statical electricity. (1040.)

1087. **Currents induced by magnets.**—If the helix in fig. 658 is connected with a galvanometer, and a bar magnet is quickly thrust into, and suddenly withdrawn from, the helix, the needle of the galvanometer indicates the movement of a current of electricity opposite in the two cases, and whose direction in each case is opposite to that of a current which, on Ampère's theory, would produce a magnet like the one employed. It is hardly needful to say that reversing the ends of the bar magnet, reverses the movements of the galvanometer. This is a case of *magnetic electric induction.*

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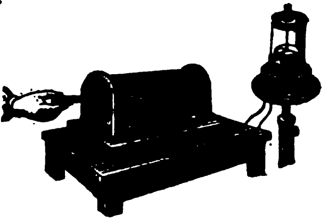

The same fact may be seen in other modes, viz.:

a. By revolving a circular plate of copper between the poles of a horse-shoe magnet, the axis of the copper being in connection in the one pole, and the edge with the other, a series of sparks may be obtained, as in Faraday's original experiment, some device being inserted to interrupt the current during the revolution.

b. By a helix on the armature of a magnet, the ends of the helix being connected with the poles respectively, on suddenly sliding the armature from the poles of the magnet, a spark is seen, and if the fingers grasp the wires at the same time, a shock follows. This fact was first announced in Dec. 1831, by Srs. Nobili and Antinori. Saxton constructed the first magneto-electric machine in which the armature, wound with a helix, was made to revolve in front of the poles of a magnet, and so to produce all the phenomena of static and voltaic electricity—an apparatus modified by Clarke, in fig. 662. Arago, in 1824, had observed the remarkable influence of a disc of copper in arresting the oscillations of a magnetic needle; an effect as we now see, thanks to Faraday, to be due to the electrical currents induced in the copper by the needle, and which reacted to restrain its oscillations.

1087. Describe the experiment, fig. 658. How else are currents induced by magnets? Who made this discovery? What did Saxton construct? What was Argo's observation on the influence of copper?

1038. **The earth's magnetism also induces electrical currents** in metallic bodies in movement; another of the numerous interesting discoveries of Faraday. A helix in the form of a ring, is made to revolve with its axis at right angles to the magnetic meridian, and consequently each point of the ring describes circles parallel to the plane of this meridian. A pole changer on the axis is so arranged as to keep the induced current moving always in the same direction; when so arranged, and its terminal wires connected with a galvanometer, a deviation of the needle indicates the flow of a current to the east or the west, according to the direction of the rotation.

1039. **Identity of electricity from whatever source.**—It follows from all that has been said, that the phenomena of magnetic, static, and dynamic electricity, are all capable of being produced each by the other; and the conclusion seems warranted that electricity, from whatever source, is one and the same power. Numerous and instructive forms of apparatus have been devised to demonstrate this point, as well also as to illustrate in detail, the principles we have, for want of space, been compelled to state in terms too concise. The student and teacher will find it useful to consult the figures of Davis's Manual of Magnetism for various forms of apparatus, due to the ingenuity of Faraday, Dr. Page, and many others. For works of standard authority, he is referred to Faraday's experimental researches, and De La Rive's treatise on electricity, each in three volumes.

We conclude this chapter by a notice of two pieces of apparatus illustrative of the principles of induction, viz: Ruhmkorff's induction coil, and Clarke's magneto-electric apparatus.

1040. **Ritchie's Ruhmkorff's induction coil.**—It is the object of this new and most interesting apparatus to show the conversion of dynamic into static electricity. Its capacity to do this is wonderful, and its performances are among the most suprising and instructive in experimental physics. The new mode of its construction by Mr. Ritchie, of Boston, has given us an instrument very far surpassing anything before known in the machines made by the celebrated Ruhmkorff, of Paris. The cause of this superiority is due chiefly to the mode of winding the fine wire coil, by which it is possible to use with success a wire of eighty thousand feet in length, while the limit in the instru-

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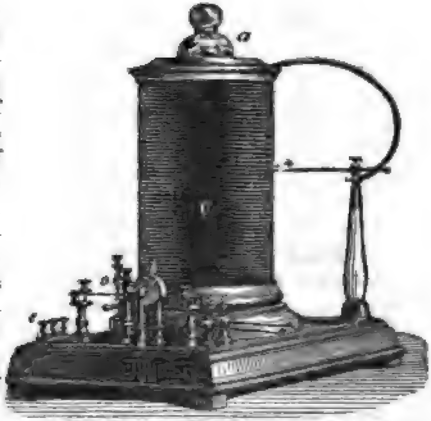
1038. What is said of the earth's magnetism inducing electrical currents? 1039. What is said of the identity of electricity from various sources? 1040. What is Ruhmkorff's induction coil?

ments made by Ruhmkorff, has been about ten thousand feet. The extreme length of spark obtained by the European instruments, was, for the French, about *two* inches, (Jean's,) and for the English, *four* inches, (Hearder's); the American instruments have projected a torrent of sparks over *twelve* inches in free air, and the one shown in fig. 659, has a capacity of about nine inches.

659



The chief parts of this apparatus are the two coils, an interruptor to the primary circuit, and the condenser. This last appendage consists, in the instrument figured, of one hundred square feet of tin foil, divided into three batteries, (two of 30, and one of 40 feet,) whose termini are at *e*. The tin foil of the condenser is carefully insulated by triple folds of varnished tissue paper, and laid away in the base of the instrument. The object of the condenser (which is due to Mr. Fizeau) is to destroy by induction the greater part of the force of the *extra-current*, (1036,) which, owing to the very powerful magnetism developed in the core of soft iron within the battery coil, would otherwise greatly impair the power of the apparatus, as it moves in a sense opposite to the primary current. In the instrument figured, over sixty-eight thousand feet of silk covered copper wire, the softest and purest possible, twelve thousandths of an inch in diameter, (No. 32 of the wire gauge,) is wound upon the exterior bobbin, *C*. About two hundred feet of wire, one-seventh of of an inch in diameter, (No. 9,) forms the inducing wire, whose ends + and — are visible in the binding screws. A heavy glass bell, *a*, insulates the coils from each other and its foot is turned outwards by a flanch as wide as the thickness of the coil. The induction coil is also incased in thick gutta-percha. The ends of this coil (which

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What is Ritchie's improvement in it? Describe its chief parts. What is the construction and the use of the condenser? How is the intensity coil wound and insulated?

are at the opposite ends of the bobbin) are carried by gutta-percha-covered conductors, to two glass insulating stands, (only one of which is visible in our figure,) where they end in sliding rods pointed with platinum at one end, and having balls at the other. The interruptor devised by Mr. Ritchie, is the toothed wheel, *b*, which raises a spring hammer, the blows of which fall upon the anvil, *o*, breaking contact between two stout pieces of platinum. The European machines are provided with a self-acting break piece; but experience has shown by comparative trials, that there is an advantage in varying the rapidity of the interruptions, according to the class of effects to be produced, and that a certain time is requisite for the complete charge and discharge of the soft iron wires, longer than the automatic break piece allows. It will be readily understood, that little justice in our narrow limits can be done to the performances of this remarkable apparatus, when Du Moncel has found it expedient to write a book of two hundred and twenty pages, devoted exclusively to a description of its principles and performances.

The *battery force* needed to excite this apparatus is only two or three large sized cells of Bunsen's battery.

1041. **Effects of the induction coil.**—The *physiological effects* are so distressing and even dangerous, that too great care cannot be taken to avoid them. M. Quet, was confined to his bed for some time, after having accidentally received the shock. Small animals are instantly killed by its discharge.

The luminous effects.—When a series of sparks passes between the points of platinum, or between the balls, they are of a zigzag form, and accompanied by a loud noise and a strong odor of ozone. Their color is violet and yellowish. If the points are within an inch or two, the stream of sparks appears to be continuous, and if blown by the breath, or by a bellows, it is deflected into a curve, and a bright flame is seen projected for some distance beyond the purple or violet stream of electric light. The color of the flame varies with the nature of the electrodes. (987.) If one of the electrodes is covered by a small glass flask, the power of the induction is such that a stream of violet electricity is seen, as it were, to pass directly through the glass, while the ball of the flask is seen covered with a magnificent net-work of violet light, spread out like the blood vessels upon the eye-ball.

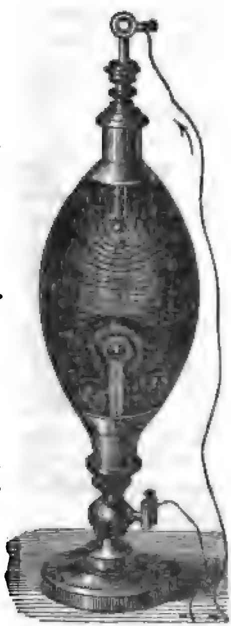
If an Æpinus condenser, or a Leyden jar, is put in the path

What excites it? 1041. What are the physiological effects of this apparatus? What are its luminous effects?

of the current, while the length of the spark is diminished thereby about three-fourths, its intensity and splendor are increased twenty fold. The electric light then becomes intensely white, and the sound of the explosion of the successive sparks, is like the snap of fulminating mercury, or the sound of a pistol. If a Newton's chromatic disc is caused to revolve before it, each spark causes the colors of the revolving disc to appear stationary, although without this evidence of an intermittent character, the stream of electricity would appear to be unbroken.

In a vacuum tube, or the electrical egg well exhausted, a torrent of rosy or violet fire falls, from the positive electrode above, toward the negative, which is surrounded with a blue and white light, extending down the stem, with splendid fluorescence. (846.) If the vacuum is made upon vapor of turpentine, or of phosphorus in the egg, a most wonderful phenomena shows itself; *the statification of the electrical light* in alternate bands of light and darkness, surrounding and depending from the positive pole, as indicated in fig. 660. Vapor of alcohol, wood-naptha, biclorid of tin, or bisulphid of carbon, may be used, each with a different effect.

660

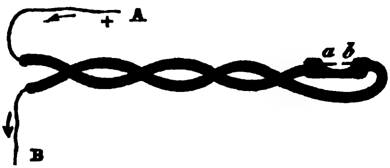


Splendid phenomena of fluorescence with canary colored glass—chemical decompositions, deflagrations of the leaf metals, discharges of flashes of lightning over the surface of a metallic mirror, a gilded board, or wet table, and numerous other most beautiful and instructive experiments are made with this apparatus. Indeed, nearly all the phenomena of static electricity are shown by it, and some of them with a power which no frictional apparatus can approach It is curious to observe, that the sparks of this kind of electricity pass freely from pointed wires. (925.)

What is said of the compound nature of the spark? How is it made more intense? What is its effect in a vacuum? Describe the statified light, and its conditions? About which pole is it statified? What other phenomena are named?

Electrical blasting by Ruhmkorff's coil is easily accomplished by the use of Stateham's fuse, fig. 661, which is only an interrupted conductor, *A B*, in which the discharge at points, *a b*, buried in the gun powder, produces its combustion, even at a distance of many miles, and in many distinct mines, or blast holes, at the same instant. This mode of blasting was lately applied on an extended scale in the construction of the great fortifications at Cherbourg, by Napoleon III.

661



1042. **Clarke's magneto-electric apparatus.**—This apparatus consists of a powerful magnetic battery, *A*, fig. 662, clamped on the upright board, *E*, by the clamp *C*. The wheel, *F*, puts in motion two helices, *H G*, wound upon a rotating armature of soft iron. The electrical current induced in the coils is interrupted by the spring, or hook, *Q*, which rubs on the interrupted back piece, *H*, while the circuit is completed by the hook, *O*, passing upon the continuous part of the spindle, *R*. A stout wire, *T*, movable at pleasure, connects the two sides, *M* and *N*, otherwise insulated by the piece of dry wood, *L*. When the coils are rapidly rotated before the poles of the magnet, the current is interrupted twice in every revolution by the hook, *Q*, with the production of a brilliant spark. If the coils are composed of a long and fine wire, then powerful shocks will be experienced by one holding the handles *R* and *S*, but capable of a great graduation, by changing the position of the break piece, *H*, with reference to the point of the revolution when it leaves *Q*. These shocks may be made quite intolerable.

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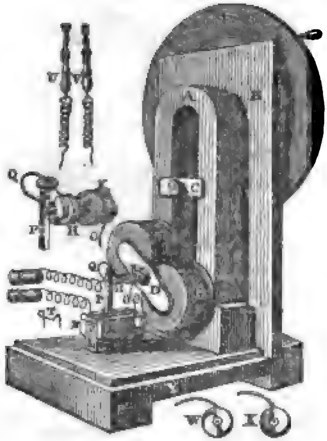
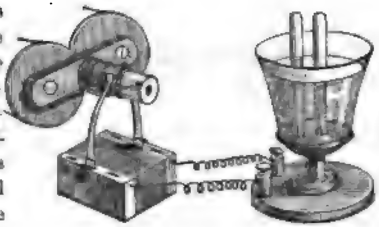


1042. Describe Clarke's magneto-electric apparatus, and its effects?

If the conducting wires of the intensity coil terminate in a decomposing apparatus, fig. 663, minute trains of gas bubbles are seen to rise from the platinum points under the tubes, showing the production of dynamic from magnetic electricity. Other effects of the intense class, as the decomposition of iodid of potassium, may also be produced with it. Substituting a coil of large wire, not over two hundred feet long, for the small long wire, the *quantity armature* is produced, from which brilliant sparks, the deflagration of mercury, and seting fire to ether, as in fig. 664, may be produced; mercury, in a copper spoon, *B*, is touched by the revolving points, *A*, on the end of the axis, *d*, and with every disruption of the circuit, the extra current discharges with splendid effect. A platinum wire may also be ignited, and electro-magnets charged by the same armatures. Thus we see all the effects of electricity, physical and physiological, coming from a magnet.

663



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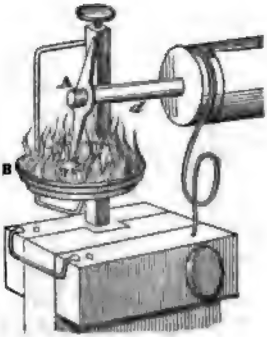

OTHER SOURCES OF ELECTRICAL EXCITEMENT INCLUDING THERMO-ELECTRICITY AND ANIMAL ELECTRICITY.

1048. **Universality of electrical excitement.**—Every change in the physical or chemical condition of matter, seems to be attended with electrical excitement. This is evident from the phenomena attending the cleavage, or pulverizing, of many minerals and crystallized substances, as mica, sugar, zinc-blende, and numerous other substances which evolve light when suddenly cleaved. If precautions are taken to insulate these, as with mica it is easy to do, by sealing wax, they also show the effects of electrical excitement by the condenser. The production of crystals is often also accompanied by electrical light.

1048. What is said of the causes of electrical excitement?

Combustion, evaporation, the escape of gas attending chemical transformations, chemical decompositions and combinations, have all been known to evolve electricity when properly observed; but in most such cases, the phenomena are too complicated to render it clear to which, if indeed to any single action of those enumerated, the excitement is due.

The electrical currents set up by heat, (thermo-electricity,) and those arising from the phenomena of life, (animal electricity,) are the most important of all sources of electricity not before dwelt on, and to them we will now briefly advert.

1044. **Thermo-electricity.**—The discovery of this source of electrical currents is due to Seebeck, of Berlin, in 1822. He found that if two metals of unlike crystalline texture and conducting power are united by solder, and the point of junction is either heated or cooled, an electrical current is excited, which flows from the point of junction to that metal which is the poorer conductor. Fig. 665 shows such an arrangement of two little bars of bismuth and antimony. When the junction, *e*, is heated, a current of positive electricity flows from the bismuth, *b*, to the antimony, *a*. If the form of a rectangle is given to this arrangement, as in fig. 666, an instrument resembling Schweigger's multiplier is formed, (1010,) by which the magnetic needle is deflected. The thermo-electric multiplier of Nobili and Melloni, or thermoscope, (521, 543,) is formed of about fifty minute bars of antimony and bismuth, soldered together at their alternate ends. Degrees of temperature otherwise inappreciable are accurately measured by the influence of the thermo-electric current excited in this apparatus, and multiplied in the galvanometer. (fig. 628.) A twisted wire also produces a thermo-electric current when the twisted portion is gently heated, and other solids, besides metals and even fluids, give rise to this species of electricity. The order in which the metals stand in reference to this power is wholly unlike the Voltaic series, and appears related to no other known prop-

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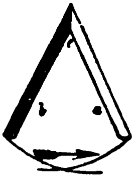

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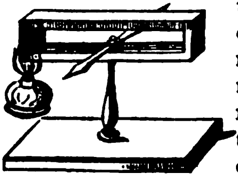


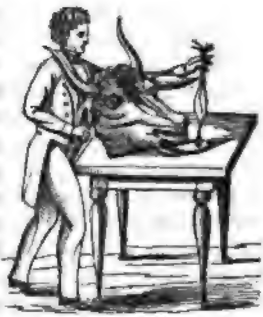
In what physical and chemical changes does electrical excitement show itself? 1044. What is thermo-electricity? Who discovered it, and when? How is its existence demonstrated? What is Nobili's thermoscope? How do the metals take rank in this respect?

erty of these elements. The rank of the principal metals in the thermo-electric series is as follows, beginning with the positive: bismuth, mercury, platinum, tin, lead, gold, silver, zinc, iron, antimony. When the junction of any pair of these is heated, the current passes from that which is highest to that which is lowest in the list, the extremes affording the most powerful combination.

If we pass a feeble current of electricity through a pair of antimony and bismuth, the temperature of the system rises, if the current passes from the former to the latter; but if from the bismuth to the antimony, cold is produced in the compound bar. If the reduction of temperature is slightly aided artificially, water contained in a cavity in one of the bars may be frozen. Thus we see that as change of temperature disturbs the electrical equilibrium, so conversely the disturbance of the latter produces the former.

1045. **Animal electricity.**—The researches of Galvani early established the existence of currents of electricity in the animal organism, flowing from the external, or cutaneous, to the internal, or mucous, surfaces of the body. Aldini, who was a zealous advocate of Galvani's claims, during the controversy between the followers of Galvani and Volta, demonstrated the existence of such a current by the legs of a frog, the lumbar nerve being brought in contact with the tongue of an ox lately killed, while the hand of the operator, fig. 667, wet with salt water, grasps an ear of the animal, to complete the circuit. The legs are then convulsed as often as the nerves touch the mucous surface of the tongue. The same delicate electroscope also shows similar excitement when its pendulous ischiatic nerves touch the human tongue, the toe of the frog being held between the moistened thumb and finger of the experimenter. Or, when, as Aldini showed, contact is made between the muscles of the thigh and the lumbar nerves by bending the legs of a vigorous frog, contractions immediately follow.

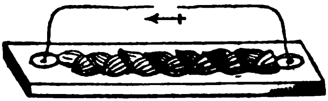
667



How may water be frozen by a reversed current? 1045. What is animal electricity? Give Aldini's experiments.

Matteucci, of Pisa, in 1837, (forty years after Galvani's result was obtained,) has the merit of reviving Galvani's original and correct opinion as to the vital source of this electricity. He demonstrated, that a current of positive electricity is always circulating from the interior to the exterior of a muscle, and that although the quantity is exceedingly small, yet by arranging a series of muscles, having their exterior and interior surfaces alternately connected, he produced sufficient electricity to cause decided effects. By a series of half thighs of frogs, arranged as in fig. 668, he decomposed the iodid of potassium, deflected a galvanometer needle to 90°, and by a condenser caused the gold leaves of an electroscope to diverge. The irritable muscles of the frog's legs form an electroscope fifty-six thousand times more delicate than the most delicate gold leaf electrometer. Du Bois Raymond, of Vienna, has demonstrated the existence of those currents in his own person by the use of the galvanometer.

668



1046. **Electrical animals.**—In some marine and fresh water animals, a special apparatus exists, adapted to produce at pleasure powerful currents of statical electricity, either as a means of defence, or of capturing their prey. Of these, the electrical eel of Surinam, first described by Humboldt, and the *cramp-fish*, or torpedo, a flat fish found on our own coast, are the most remarkable. They have an alternate arrangement of cellular tissue and nervous matter in thin plates of a polygonal form, constituting a perpetually charged electrical battery, arranged in the manner of a pile. By touching their opposite surfaces, a very violent shock is received, such as to disable a very powerful man, or even a horse. Prof. Matteucci has shown us how to charge a Leyden jar, by placing the torpedo between two plates, arranged like the plates of a condenser; and Faraday has published an interesting account of his experiments with the eels of Surinam, from which he not only obtained shocks, but made magnets, deflected the galvanometer, produced chemical decompositions, evolved heat and electrical sparks. (Expt. Res., 1749-1795.) The student is also referred to Prof. Matteucci's interesting 'Lectures on Living Beings,' for further details on this very

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Who revived Galvani's views? Give his results. 1046. What is said of electrical animals? Who have investigated this subject?

interesting subject, and to a memoir, on the American Torpedo, (Dr. D. H. Storer, Sill. Jour. [1] xlv. 164.)

METEOROLOGY.

1047. **Meteorology** is that branch of natural philosophy which treats of the atmosphere and its phenomena. The subject may properly be divided into three parts. 1st, Aerial phenomena, comprehending winds, hurricanes and water spouts. 2d, Aqueous phenomena, including fogs, clouds, rains, dew, snow and hail. 3d, Luminous and electrical phenomena, as lightning, aurora-borealis, rainbows: to which may be added meteorics tones and shooting stars.

Before commencing the consideration of the phenomena above mentioned, a few words will be said of the distribution of temperature over the surface of the earth.

1048. **Climates, seasons.**—By *climate* is meant the condition of a place in relation to the various phenomena of the atmosphere, as temperature, moisture, &c. Thus we speak of a warm climate, a dry climate, &c.

A *season* is one of the four divisions of the year, spring, summer, autumn and winter. Astronomical seasons are regulated according to the march of the sun. In meteorology it is sought to divide them according to the march of temperature. Winter being the most rigorous of seasons, it is so arranged that its coldest days (about January 15th) fall in the middle of the season. Hence winter consists of December, January and February; spring of March, April and May, &c. Few meteorologists have regard to the astronomical divisions, which make winter begin December 21st.

1049. **Influence of the sun.**—The sun is the principal cause that regulates variations in temperature. In proportion as this luminary rises above the horizon, the heat increases; it diminishes as soon as it sets. The temperature, also, depends on the time it remains above the horizon. The sun, in winter, sends its rays obliquely upon the earth, and at this season, therefore, less heat is received than in summer, when its rays are more nearly perpendicular, (572; 3d.) Mathematicians have in vain endeavored

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1047. What is meteorology? How is it divided? 1048. What is climate and what the common significance of season? 1049. How does the sun influence the climate?

to deduce the temperatures of days and seasons from the height of the sun above the horizon. This failure is owing to many accidental and local causes which modify the result.

1050. **Means of temperature.**—The mean or average daily temperature is commonly obtained by observing the standard thermometer at stated times during the day, and then dividing the sum of these temperatures, respectively, by the number of observations. The lowest temperature of the day occurs shortly before sunrise, the highest a few hours after noon. The mean daily temperature, at Philadelphia, is found to be one degree above the temperature at 9 A. M.

By taking the average of all the mean daily temperatures throughout the year, the mean annual temperature is obtained.

1051. **Variations of temperature in latitude.**—The average annual temperature of the atmosphere diminishes from the equator towards the poles. But the temperature is not the same for places in the same latitude in the two hemispheres, as is seen in the following table.

Places.	Latitude.	Temp	Places.	Latitude.	Temp.
Falkland Isles,	51° S	47° 28	London.	51° 31′ N	50° ·72
Buenos Ayres,	34° 36′ S	62° 6	Savannah,	32° 05′ N	64° ·58
Rio Janeiro.	22° 56′ S	73° 96	Calcutta,	22° 35′ N	78° ·44

This variation is owing to a variety of local causes, such as the elevation and form of the land, proximity to large bodies of water, the general direction of winds, &c.

1052. **Variation of temperature in altitude.**—The temperature of the air diminishes with the altitude. As a general rule, it may be stated that there is a diminution in temperature of 1° F. for every 343 feet of elevation. On rising from near the level of the sea, the rate of decrease is more rapid; after a certain height is reached, it proceeds more slowly; but in very elevated regions, it again increases.

1053. **Limit of perpetual snow.**—It follows from what has just been stated, that in every latitude, at a certain elevation, there must be a point where moisture once frozen must ever remain congealed. The lowest point at which this is attained is called the limit of perpetual snow, or the snow-line. This point is

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1050. What are means of temperature? Give examples. 1051. Does temperature vary with latitude? 1052. How with altitude?

highest near the equator, and sinks towards either pole, as is shown in the table below.

Places.	Latitude.	Snow lines.
Straits of Magellan,	54° S	3,760 feet
Chili,	41° S	6,009 "
Quito,	00°	15,807 "
Mexico,	19° N	14,768 "
Ætna,	37° 30′ N	9,531 "
Kamtschatka.	56° 40′ N	5,248 "

1054. **Isothermal lines.**—If all the points whose mean temperature is the same are connected by lines, a series of curves are obtained, which Humboldt was the first to trace on charts, and which he has named *isothermes*, or *isothermal lines*, (from *isos* equal and *thermos* heat). The latitude and longitude are the principal conditions which determine the temperature of any point upon the earth's surface, but the influence of these conditions is greatly modified by numerous accidental and local influences: hence, the isothermal lines present numerous sinuosities instead of passing around the earth parallel to any degree of latitude. The introduction of isothermes formed an important epoch in meteorological science, for by it have been established the great laws of the distribution of heat over the surface of the earth for the four seasons. The chart of isoclinal lines, fig. 525, serves to illustrate also the general direction and place of isothermal lines, (896.)

AERIAL PHENOMENA.

1055. **Cause of winds.**—Wind is air in motion. Winds are generally caused by variations in the temperature of the earth, produced in part by the alternation of day and night, and the change of the seasons. The air, in contact with the hotter portion of the earth becomes heated, and being lighter than before, rises, while the surrounding air rushes in below to supply its place. The revolution of the earth, on its axis, also comes in as an important modifying cause of the thermal conditions. Winds are also, sometimes, caused by the sudden displacement of large volumes of air, as in the fall of an avalanche, and by a rapidly moving railway train.

1053. Give the limits of perpetual snow in the table. 1054. What are isothermal lines? To what are these related? 1055. What causes produce winds?

Winds are divided into three classes, viz., regular, periodical and variable.

1056. **Regular winds** are those which blow continuously in a nearly constant direction, as the trade winds.

Trade winds occur in the equatorial regions, on both sides of the equator to about the 30° of latitude. Those in the northern hemisphere blow from the north-east to the south-west; those in the southern hemisphere from the south-east to the north-west.

These winds are produced by the unequal distribution of heat upon the surface of the earth, and by the rotation of the earth on its axis. From the vertical position of the sun, the equatorial regions are intensely heated, the temperature gradually diminishing towards the poles. The heated air, above the equator, rises and blows off in the upper regions of the atmosphere towards either pole. At the same time, currents are established on the surface of the earth to supply to the equatorial regions the air which the upper currents have carried off. If the earth was at rest, these winds would blow due north and south. But the earth is revolving on its axis, from west to east, at the equator; therefore, the eastern velocity is greatest, but ti gradually diminishes towards the poles. In consequence of this, the wind blowing from the north pole, towards the equator, acquires a westerly direction, and seems to come from the north-west, and for the same reason, the wind blowing from the north-pole towards the equator, acquires an easterly direction, and seems to come from the south-east.

1057. **Periodical winds** are those which blow regularly in the same direction, at the same seasons of the year, or hours of the day. The most interesting winds of this class, are the monsoons, and the land and the sea breezes.

The monsoons occur within, or near the tropics; they blow from a certain quarter, one half of the year, and from an opposite point during the other half. The cause of the monsoon is found in the effect produced by the sun in his annual progress from one tropic to another, successively heating the land on either side of the equator. The simoon is a periodical wind which blows over the deserts of Asia and Africa; it is noted for its high temperature, and the sand which it raises in the atmosphere, and carries along with it. This wind from the Great Sahara desert blows over Algeria and Italy, and reaches even the north shores of the Mediterranean where it receives the name of sirocco.

1056. What are regular winds? Name them. How are they produced? 1057. What are periodical winds? What are the monsoons and sirocco?

On the coasts and islands within the tropics, and to some extent in temperate regions, a *sea breeze* daily occurs flowing from the sea to the land during the day; as it gradually subsides, it is succeeded by a *land breeze*, flowing from the land to the sea. In some places these breezes are scarcely perceptible beyond the shore; in others, they extend inland for miles.

The causes of the land and sea breezes are very apparent. During the day, while the sun shines, the land acquires a higher temperature than the water of the surrounding ocean. The air, above the land, becomes heated, and rises. To supply the place of that which has risen, air flows in from the sea, constituting the sea breeze. But when the sun descends, the land rapidly loses its heat, by radiation, while the temperature of the ocean is scarcely changed. In consequence of this, the air above the land becomes cooled, and therefore more dense, and flows towards the water, constituting the land breeze. At the same time, in the higher regions of the atmosphere, air flows in from the sea to the land.

1058. **Variable winds** are those which blow sometimes in one direction, sometimes in another. The direction of winds is influenced by numerous causes, as the nature and form of the surface of the earth, the proximity of large bodies of water, &c. In these latitudes, the direction of the prevailing winds is from the north-west to the south-east.

1059. **Hurricanes** are terrific storms often attended by thunder and lightning; they are distinguished from every other tempest by their extent, their power, and the sudden changes in their direction. From numerous observations, "it appears that hurricanes are storms of wind, which revolve around an axis, upright or inclined to the horizon, while at the same time the body of the storm has a progressive motion over the surface of the earth." This law has been established by Redfield and Reid. Their progressive velocity varies from ten to thirty miles per hour; the rotatory velocity is sometimes as much as a hundred miles per hour. The diameter of a hurricane is from a hundred to five hundred miles, though sometimes, as in the Cuban hurricanes, it is much more.

1060. **Tornadoes or whirlwinds** are distinguished from hurricanes, chiefly in their extent and continuance. They are rarely more than a few hundred rods in breadth, and their whole track is seldom more than twenty-five miles in length. The continu-

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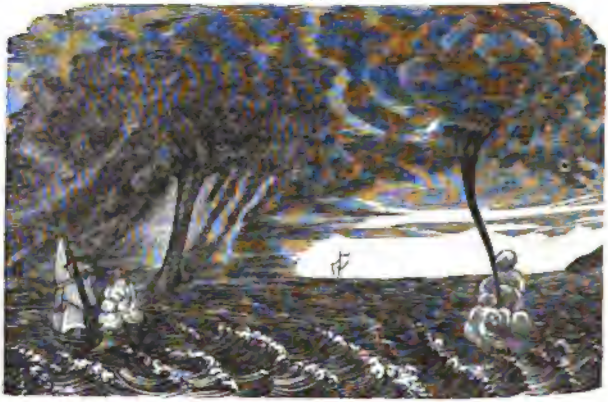
What causes land and sea breezes? 1058. What are variable winds? 1059. Describe hurricanes. What is their extent and velocity? 1060. What are tornadoes, their limits and duration?

ance of tornadoes is but a few seconds at any one place. They are oftentimes of great energy, uprooting trees, overturning buildings, and destroying crops.

1061. **Waterspouts** differ from whirlwinds in no other respect than that water is subjected to their action, instead of bodies, upon the surface of the land.

Waterspouts first appear as an inverted cone, extending downward from a dark cloud. As the cone approaches the water, the latter becomes agitated, the spray rises higher and higher, and finally both uniting, there is formed a continuous column from the cloud to the water, usually bent as in fig. 669, but sometimes erect. After a little time, the column breaks, and the phenomena disappear. As to the origin of waterspouts, philosophers are divided. Kaemtz, a distinguished German meteorologist, assumes that they are principally due to two opposite winds, which pass side by side, or when a very brisk wind prevails in the higher regions of the atmosphere, while it is clear below. Peltier, and other physicists, ascribe waterspouts to an electrical cause.

669



Waterspouts are in great part formed of atmospheric water, as is shown by the fact, that the water escaping from them, is not salt even in the open sea. If the atmosphere is not moist, there is no condensation of vapor, and the only noticeable phenomena is the violence of the wind and its rotatory motion.

1062. **Anemometers** are instruments designed to measure the velocity of winds. Waltmann's anemometer is one of the best

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1061. What are waterspouts? To what causes ascribed?

It consists essentially of a small wind-mill, to which is attached an index marking the number of revolutions per minute. The stronger the wind, the greater the number of revolutions made. The necessary data for ascertaining correctly with this instrument the velocities of winds, are easily obtained as follows. Nothing more is necessary, than on a calm day, to travel with the apparatus on a carriage or rail car, observing the number of revolutions made in going any known distance in a given time. The effect will be the same as if the air was in motion. A table is then constructed, indicating the velocity of a wind which turns the sails forty, fifty, sixty, or more times per minute.

1063. **The velocity of winds** varies from that which scarcely moves a leaf, to that which overthrows the staunchest oak. Smeaton has classified winds as follows, according to their velocity and power.

Velocity of the wind. Miles per hour.	Perpendicular force on one sq. ft. in lbs. avoirdupois	Common appellation of such winds.
1	.005	Hardly perceptible.
4	.079	Gentle wind.
5	.123	
10	.492	Pleasant brisk gale
15	1.107	
20	1.968	Very brisk.
25	3.075	
30	4.429	High wind.
35	6.027	
40	7.873	Very high.
50	12.300	Storm.
60	17.715	Great storm.
80	31.490	Hurricane.
100	49.200	Violent hurricane.

AQUEOUS PHENOMENA.

1064. **Humidity of the air.**—Vapor of water is always contained in the air. This may be demonstrated by placing a vessel filled with ice or a freezing mixture in the atmosphere; in a little time the vapor from the air will be condensed on the walls of the vessel, in the form of minute drops of water, (626.)

Air is said to be *saturated with moisture* when it contains as much of the vapor of water as it is capable of holding up at a given tem-

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1062. What are anemometers? How are they graduated? 1063 What is the velocity of various winds enumerated in the table? 1064. What is said of the humidity of the air?

perature. That the capacity for moisture is greater as the temperature increases, is shown in the following table.

A body of air can absorb
At 32° F. the 160th part of its own weight of watery vapor.
" 59° " " 80th " " " "
" 86° " " 40th " " " "
" 113° " " 20th " " " "

It will be noticed that for every 27° of temperature above 32°, the capacity of air for moisture is doubled. From this it follows that, while the temperature of the air advances in an arithmetical series, its capacity for moisture is accelerated in a geometrical series.

1065. **Absolute humidity; relative humidity.**—The term absolute humidity of the air has reference to the quantity of moisture contained in a given volume. The absolute humidity is greatest in the equinoctial regions, and diminishes towards either pole; it diminishes, also, with the altitude, but the true ratio is not fully known. The absolute humidity is also greater on coasts than inland, in summer than in winter, and less in the morning than about midday.

The term *relative humidity* has reference to the dampness of the atmosphere, or its proximity to saturation. This state is dependent upon the mutual influence of absolute humidity and temperature. The atmosphere is considered dry when water rapidly evaporates, or a wet substance quickly dries. The expressions wet and dry convey simply an idea of the relative humidity of the atmosphere, and have no reference to the absolute quantity present, for a damp air is rendered dry by raising its temperature, and a dry air damp by cooling it.

1066. **Hygrometers** are instruments by which the humidity of the atmosphere is determined. They are of various kinds, and may be classified as follows: chemical hygrometers, absorption hygrometers, condensation hygrometers and psychrometers.

All hygroscopic substances (viz., those which have an affinity for water) are chemical hygrometers. The amount of moisture in the air is determined with these subtances, by filling a tube with chlorid of calcium, for example, and passing a known volume of air through it; the increase in weight of the tube, after the experiment, indicates the weight of moisture present in the air. This method yields the best results, but is difficult of execution.

How much vapor of water can it absorb at different temperatures? 1065. How are terms absolute and relative humidity to be understood? 1066. What are hygrometers? What is the chemical mode of hygrometry?

Hygrometers of absorption are founded on the fact that certain organic substances elongate in a humid atmosphere, and contract in a dry atmosphere. Saussure's hygrometer, fig. 670, consists of a metal frame, in which is hung a hair, *c*. This hair is fastened at its upper end, *d*, to a screw, *a b*, the other end passes over a pulley, *o*, and is stretched tight by a silk thread, and a weight, *p*, also attached to the pulley. The axis of the pulley carries a needle, which moves over a graduated scale as the hair is lengthened or shortened. The instrument is graduated by marking zero at that point on the scale at which the needle stops when the apparatus is placed in a perfectly dry atmosphere, and one hundred, at the point the needle marks in an atmosphere saturated with moisture. The interval between these two points is then divided into one hundred equal parts, which indicate different degrees of humidity.

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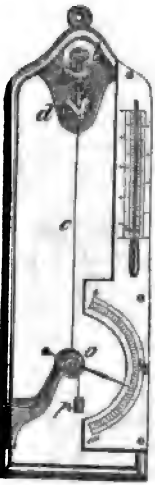

Founded on the same principle as the instrument above described, are *hygroscopes;* these show whether there is more or less moisture in the atmosphere, but furnish no indication of its amount. They are usually made in the form of a human figure. If much moisture is present, a cord within the apparatus, increases in length, and draws up over the head of the figure an umbrella or hood; as the air becomes less humid, the cord contracts, and the covering falls. Some seed-vessels, as the capsules of a species of *hibiscus*, common in Asia Minor, act as sensitive hygroscopes, opening and closing with changes of moisture long after they have been removed from the plant.

Of condensation hygrometers, the best known is Daniell's, fig. 671. It consists of a glass tube bent twice at right angles, having a bulb at either extremity. The bulb, *A*, is partly filled with ether, into which is inserted the ball of a delicate thermometer inclosed in the stem of the instrument. The tube is filled with the vapor of ether, the air having been driven out. The bulb, *B*, is covered with fine muslin. Upon the supporting pillar, a second, thermometer is placed. In order to determine the dew point, or hygrometric state of the atmos-

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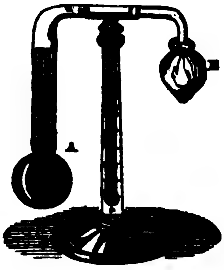

Describe Saussure's hygrometer? What are hygroscopes? Give examples.

phere, by this instrument, a few drops of ether are allowed to fall upon the muslin-covered bulb, evaporation of the ether takes place, the bulb is cooled, and condenses the etherial vapor within. In conseqence of this effect, the ether in *A* evaporates, causing a reduction of temperature indicated by the internal thermometer. At a certain point the atmospheric moisture begins to form in a ring of dew upon the bulb *A*. The difference at this moment between the degrees indicated by the two thermomoters, denotes the relative humidity of the atmosphere; the difference is greater, the dryer the air.

Regnault's hygrometer depends on the same principle as Daniell's instrument; but in place of the black and vacuous glass, he employs two thin tubes of polished silver.

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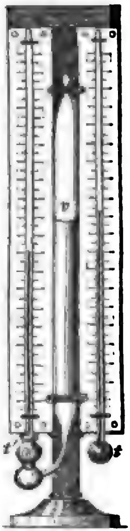

Psychrometers, or ***hygrometers of evaporation***, are founded on the rapidity of the evaporation of water in the air. August's psychrometer, fig. 672, is very commonly used; it consists of two similar thermometers, *t' t*, placed side by side, supported on a frame. The bulb of *t'* is covered with fine muslin, the lower end of which dips into a small vessel, *v*, like a bird-glass, containing water; by this arrangement the bulb is continually kept moist. Evaporation takes place from the moistened bulb, with a rapidity varying with the humidity of the atmosphere, and a corresponding depression in the temperature of the thermometer is produced. The hygrometric state of the atmosphere is determined from the observed difference in the two thermometers by the use of a formula, for which reference may be had to the "Smithsonian Instructions for meteorological observations," or to "Boyé's Pneumatics," p. 110. These instruments are made on the Smithsonian model by James Green, of New York, whose barometers have been before referred to, (827.)

1067. **Fogs**, or **mists**, are visible vapors that float in the atmosphere, near the surface of the earth.. Fogs are produced by the union of a body of cool air with one that is warmer and humid. Many philosophers, as Saussure and Kratzenstein, consider that the globules, or vesicles, of which a fog is composed, are hollow, the water serving only as an envelope; it is probable, if this is true, that the vesicles are mixed with a great quantity of drops of water.

Describe Daniell's hygrometer, fig. 671. What are psychrometers, and how used? Describe August's psychrometer.

1068. **Clouds are masses of vapor that float in the upper regions of the atmosphere.** They are distinguished from fogs only by their altitude; they always result from the partial condensation of the vapors that rise from the earth. As clouds often float in regions whose temperature is many degrees below the freezing point, they are sometimes, no doubt, composed of frozen particles.

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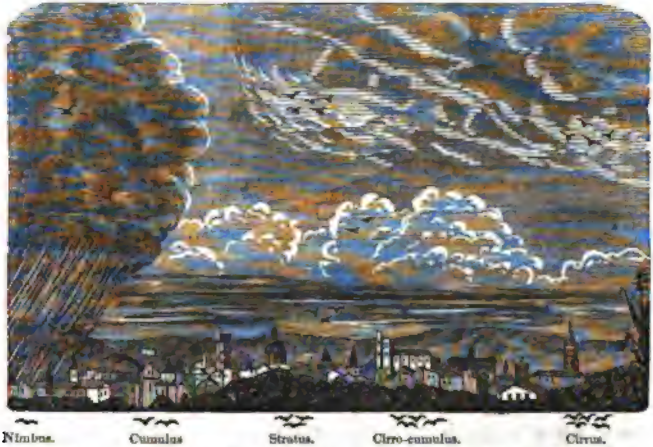

1069. **Classification of clouds.**—Clouds are generally divided into four great classes, viz: the *nimbus*; the *cumulus*; the *stratus*, and the *cirrus*, as shown in the diagram, fig. 673.

The *nimbus*, or rain cloud, (nimbus, *storm*,) has a characteristic storm-like form; it is distinguished from others by its uniform grey, or blackish tint and its edges fringed with light.

The *cumulus*, (cumulus, *heap*,) appears often in the form of a hemisphere resting on the horizon as a base; oftentimes in detached masses, gathered in one vast cloud. When lighted up by the sun, they present the appearance of mountains of snow. The cumulus is the cloud of day; in the fine days of summer it is most perfect.

The *stratus*, (stratus, *covering*,) consists of sheets of cloud, or layers of vapor, stretching along and resting upon the horizon. It forms about sun-set, increases during the night, and disappears about sunrise. It floats at a moderate elevation above the earth.

The *cirrus*, (cirrus, *curl*,) usually resembles a distended lock of hair, being composed of streaks, or feathery filaments, assuming every

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1067. What are fogs? How does the vapor exist? 1086. What are clouds? 1069. Classify and describe them.

variety of figure. The cirrus floats at a higher elevation than other clouds, and probably is often composed of snow flakes.

Intermediate forms of clouds are distinguished by the names of *cirro-stratus*, *cirro-cumulus*, and *cumulo-stratus*.

1070. **Rain** is the vapor of clouds, or of the air precipitated to the earth in drops. Rain is generally produced by the rapid union of two or more volumes of humid air, differing considerably in temperature; the several portions, when mingled, being incapable of absorbing the same amount of moisture that each would retain if they had not united. If the excess is great, it falls as rain, if it is of slight amount, it appears as cloud. The production of rain is the result of the law, that the capacity of air for moisture decreases in a higher ratio than the temperature.

1071. **Rain-gauge.**—The quantity of rain that falls during a given time is measured by means of an instrument called a rain-gauge.

One of the simplest rain-gauges consists of a cylindrical copper vessel, furnished with a float; the rain falling into the vessel, the float rises. The stem of the float is accurately graduated, so that an increase in the depth of the water of one one-hundredth of an inch, is easily measured.

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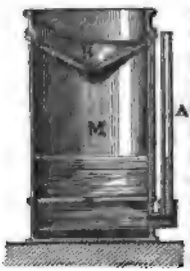

Another rain gauge, a section of which is represented in fig. 674, consists of a cylindrical copper vessel, *M*, closed by a cover, *B*, shaped like a funnel, with an aperture in the centre, through which the water passes into the interior. This cover prevents loss by evaporation. A lateral glass tube, *A*, carefully graduated, rises from the base of the vessel. The water rises in the tube to the same height as in the copper cylinder. If the apparatus has been placed in an exposed situation, for a certain time, as a month, and the gauge shows three inches of water; this indicates that the rain that has fallen during the interval would cover the earth to the depth of three inches, if it were not diminished by evaporation, or infiltration.

1072. **Distribution of rain.**—Rain is not equally distributed over the surface of the earth. As a general rule it may be stated

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1070. What is rain, and how produced? 1071. Describe the rain guage and its use.

that, the higher the average temperature of a country, the greater will be the amount of rain that falls upon it. Local causes, however, produce remarkable departures from this rule. In the tropics the average yearly fall is ninety-five inches; in the temperate zone it is thirty-five inches.

Regions without rain are not unfrequent. In Egypt, it scarcely ever rains. Along the coast of Peru, is a long strip of land upon which no rain ever descends. A similar destitution of rain occurs on the coast of Africa and some parts of North America; the intervals between the showers being six or seven years.

In Guiana it rains during a great part of the year; this is also the case, according to Davison, at the straits of Magellan. In the Island of Chiloe, (S. lat. 43°,) there is a proverbial saying, that it rains six days of the week, and is cloudy on the seventh.

1073. **Days of rain.**—The rainy days are more numerous in high than in low latitudes, as is seen in the following table, although the annual amount of rain which falls is smaller. Consequently, the ordinary rains of the tropical regions are more powerful than those of the temperate regions.

N. latitude.	Mean annual number of rainy days.
From 12° to 43°	78.
" 43° " 46°	103.
" 46° " 50°	134.
" 50° " 60°	161.

In the northern part of the United States there are, on the average, about 134 rainy days in the year; in the southern part, about 103.

1074. **Annual depth of rain.**— The greatest annual depth of rain occurs at San Luis, Maranham, 280 inches; the next in order are Vera Cruz, 278; Grenada, 126; Cape François, 120; Calcutta, 81; Rome, 39; London, 25; Uttenberg, 12·5. In our country, the average annual fall is 39·23 inches; at Hanover, N. H., 38; New York state, 36; Ohio, 36; Missouri, 38·265.

1075. **Dew** is the moisture of the air condensed by coming in contact with bodies cooler than itself. The temperature at which this deposition of moisture commences, is called the dew point. (626.) The dew point varies according to the hygrometric state

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1072. What is said of the distribution of rain in several places? 1073. What is the mean annual number of rains as quoted? 1074. What is the average annual depth of rain? 1075. What is dew, and the dew point?

of the atmosphere; being nearer the temperature of the air, the more completely the air is saturated with moisture. In this climate, in summer, the dew point is often 30° or more below the temperature of the atmosphere. In India, it has been known to be as much as 61°.

1076. **Cause of dew.**—Dr. Wells, an American, residing in England, determined by his researches the cause of dew. It may be given briefly as follows: During the day, the surface of the earth becomes heated by the sun, and the air is warmed by it. When the sun goes down, the earth continues to radiate heat without receiving any in return, and thus its temperature diminishes. The air loses its heat more slowly, and is cooled only when it comes in contact with the cooler earth. If this cooling reaches the dew point of the air, moisture is condensed in the form of small drops upon cold objects, (good conductors,) as the soil or vegetation.

1077. **Substances upon which dew falls.**—Dew does not fall upon all substances alike; in consequence of differences in radiating power, certain substances cool quicker and more perfectly than others. The dusty road, the rocks and barren soil, cool slowly, and therefore on them but little dew falls. Trees, shrubs, grasses, and vegetation of every kind, radiate heat easily, and becoming cooler, abundance of dew is deposited upon them.

1078. **Circumstances influencing production of dew.**—The most copious deposits of dew take place on cool clear nights. For when there are clouds, these radiate back the heat which has escaped from the earth, and thus prevent its cooling, and therefore no dew is deposited. The same effect results from the straw, mats, boards, &c., which gardeners use to cover delicate plants, to protect them from freezing. (See diagram 675-39°.) On a windy night there is but little dew deposited, because the air is moved away from the cold surface of any body before it has become sufficiently cooled to deposit moisture.

1079. **Frost** is frozen dew. When the temperature of the earth sinks in the night to the freezing point, the aqueous vapor then deposited congeals in the form of sparkling crystals, known as frost. Fig. 675, in which the arrows indicate the movements of heat, and the numerals the temperature of the air,

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1076. What is the cause of dew? 1077. Upon what substances does dew fall? 1078. What circumstances influence its fall? 1079. What is frost?

will render the phenomena of dew and frost more intelligible.

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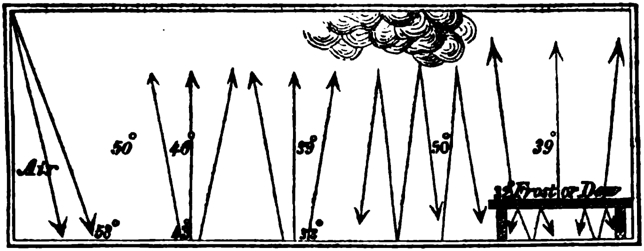

1080. **Snow** is the frozen moisture that descends from the atmosphere, when the temperature of the air at the surface of the earth is near, or below, the freezing point. The largest flakes of snow are produced when the atmosphere is loaded with moisture, and the temperature of the air is about 32°; as the cold increases, the flakes become smaller.

The bulk of recently fallen snow is ten or twelve times greater than that of the water obtained from it. Snow flakes are crystals of various forms. Scoresby has enumerated six hundred forms, and figured ninety-six. Kaemtz has met with at least twenty forms not figured by Scoresby. Crystals of snow are not solid, else they would be transparent as ice; they contain air. It is from the reflection of light from the assemblage of crystals, that its brilliant whiteness is due. Snow crystals are produced with most regularity during calm weather, without fog. Fig. 676 represents a few of the beautiful forms assumed by snow crystals.

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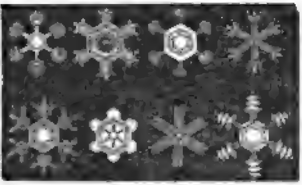

1081. **Colored snows.**—Captain Ross, in 1819, discovered a crimson snow clothing the sides of the mountains at Baffin's Bay. Raymond has observed it on the Pyrénées; it has also been seen on the Italian Alps and Appenines. Certain French meteorologists at Spitzbergen, in 1838, passed over a field covered with snow, which appeared of a green hue whenever pressed upon by the foot. These hues, it has been found, are owing to

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Explain the diagram, fig. 675. 1080. What is snow? What is said of its bulk, forms, and color? 1081. What is snow colored by?

the presence of a certain class of microscopic plants, the different hues probably representing different stages of development.

1082. **Hail** is the moisture of the air frozen into globules of ice. Hail-stones are generally pear-shaped; they are formed of alternate layers of ice and snow, around a white snowy nucleus. It is necessary for the production of hail, that a warm, humid body of air, mingle with another so extremely cold, that after uniting, the temperature shall be below the freezing point. The difficulty of explaining the phenomena of hail-storms consists in accounting for this great degree of cold.

Hail-storms are most frequent in temperate climates. They rarely occur in the tropics, except near high mountains, whose summits are above the snow line. It is in great part during the summer, and in the hottest part of the day, that hail falls. Hail-storms rarely occur at night. Hail-stones are often of considerable size; the largest are frequently an aggregation of several frozen together. Sleet is frozen rain; it occurs only in cold weather; it falls only during gales, and when the weather is variable.

ELECTRICAL AND LUMINOUS PHENOMENA.

Certain of the optical phenomena of the atmosphere have already been considered in previous paragraphs, as the rainbow, mirage, &c. (840 and 845.) The general laws of atmospheric electricity are also given in section 964. We shall now speak briefly of some of the more important electrical phenomena.

1083. **Origin of atmospheric electricity.**—The more prominent sources of atmospheric electricity are, 1st, *evaporation.*—Electricity is always produced where impure water is evaporating, and in which chemical decomposition is taking place. As ocean and other waters are generally in this condition, we have here a most abundant source of electricity. 2d, *condensation.*—When a vapor is condensed into a liquid, electricity is developed. Condensation is considered one of the most fruitful sources of electricity. 3d. *Vegetation* also furnishes electricity to the atmosphere. Pouillet has shown, that positive electricity is developed when seeds first sprout, and it escapes with the carbonic acid produced during the act of germination. The same results are probably

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1082. What is hail, its origin and mode of occurrence? 1083. What is said of the origin of atmospheric electricity?

produced throughout the life of the plant. 4th, *combustion.*—During the combustion of any substance, positive electricity escapes from it, while the substance itself is negatively electrified. 6th. *Friction*, it has already been shown is the most common cause of static electricity. Most probably, when large volumes of air encounter each other, electricity is developed by this cause, especially when the masses differ in humidity and temperature.

1084. **Aurora borealis.**—Under this name are comprised the luminous phenomena seen in the northern sky, though occasionally they have been observed also in the neighborhood of the south pole; they are there called aurora *australis.* They present, when in full display, a spectacle of surpassing splendor and beauty. The cause of the aurora borealis is yet involved in obscurity. Although it is, evidently, intimately connected with magnetic electricity, it is impossible to say what this connection is. (896.) It has been ascribed to the passage of electrical currents through the upper regions of the atmosphere, the different colors being manifested by the passage of the electricity through air of different densities. (1041.)

1085. **Appearance of auroras.**—Before the aurora appears, the sky in the northern hemisphere assumes a darkish hue, which gradually deepens, until a circular segment of greater or less size is formed. This dark segment is bounded by a luminous arc, of a brilliant white color, approaching to blue.

The lower edge of this arc is clearly defined; its upper edge gradually blends with the sky. When this luminous arc is formed, it frequently remains visible for hours, but is always in perpetual motion. It rises and falls, and breaks in various places. Clouds of light are suddenly disengaged, separating into rays, which stream upwards like tongues of fire, moving backwards and forwards. When the luminous rays are numerous, and their palpitating lights pass to the zenith, they form a brilliant mass of light, called the *corona* or crown, whose centre is the point towards which the dipping needle at the place is directed. The aurora is then seen in its greatest splendor; the sky resembles a fiery dome, supported by waving columns of different colors. When the rays are darted less visibly, the aurora soon disappears, the lights momentarily increase, then diminish, and finally disappear. It is asserted that sounds, like the rustling of silk, often accompany the display of auroras, but this is extremely problemat-

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1084. What is said of the aurora? 1085. What appearances precede the aurora? Describe the aurora. 1086. What is their extent and height? What is said of that of November, 1848?

ical; the most celebrated polar navigators never heard any noises which they could certainly ascribe to the auroras.

1086. **Extent and height of auroras.**—The aurora is not a local phenomenon; it is often beheld simultaneously in places far apart, as in Europe and America.

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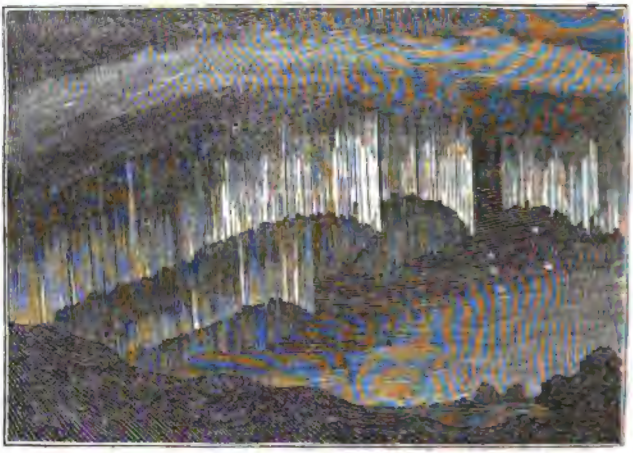

(*Auroral display, seen at Bossekop*, 70° *N.* 1838–9.)

In 1796, a beautiful aurora was observed simultaneously in Pennsylvania and France. The aurora of January 7th, 1831, was observed in all central and northern Europe, and at Lake Erie. The aurora of November 17, 1848, is probably the most remarkable hitherto recorded. It was seen from Odessa, on the Black Sea, lat. 46° 35′ long. 30° 35′ E. to San Francisco, (California,) 38° N. lat. 122° W. long. and as far south as Cuba. It seems everywhere to have had a prevailing red hue, mistaken in many places for a conflagration. (Sill. Jour. [2] vii. 203.) Many astronomers have endeavored to determine the height of auroras, but the results of their calculations are not certain. Earlier philosophers computed their altitude at several hundred miles; a lower limit is assigned by later observers. A brilliant auroral arch was observed in the northern and middle states, April 7th, 1847; from the observations made at Hartford and New Haven, Conn., its height was computed by Mr. E. C. Herrick, of the latter place, to be nearly one hundred and ten miles.

1087. What of the frequency of auroras? What periods are named? What are Herrick's results at New Haven?

1087. **Frequency of auroras.**—Auroras are more frequently seen in winter than in summer; but this circumstance does not indicate that during the former season there are actually a greater number, for the increased length of night would render a greater number visible, even if they were equally distributed throughout the year. About the period of the equinoxes they appear to be more frequent than at other times.

In addition to the annual period, there appears to be another, a secular period, extending through a number of years. One of these periods was comprised between 1717 and 1790; its maximum was obtained in 1752. An increase in the frequency of auroras began again in 1820. Prof. Olmsted, in an important paper on this subject, in the Contrib. of Smithson. Inst. vol. 8, fixes one of these secular periods between August 27, 1827, and November, 1848, or a little later. The number of auroras, observed for a period of twelve years, at New Haven, by Mr. E. C. Herrick, is given in the following table.

	Number of auroras.
From May 1838 to May 1839,	35
" " 1839 " " 1840,	36
" " 1840 " " 1841,	36
" " 1841 " " 1842,	21
" " 1842 " " 1843,	7
" " 1843 " " 1844,	7
" " 1844 " " 1845,	12
" " 1845 " " 1846,	20
" " 1846 Dec. 1847,	44
January 1848 " 1848,	45
" 1849 " 1849,	17

1088. **Disturbance of the magnetic needle.**—During an auroral display, the compass needle is often much disturbed. (885.) Sometimes it is deviated several minutes, or degrees, to the east; then it is agitated and returns.

The oscillations of the needle are as variable as the aurora; when the arch is quiet, the needle is motionless; its disturbance commences when the streamers begin to fly. During the aurora of November 14th, 1837, the entire range of the needle was observed by Messrs. Herrick and Haile to be nearly 6°. According to Wilke, the position of the dipping needle is as variable as the compass needle; the former rising and falling with the corona.

1089. **Lightning.**—It has already been stated, that air subjected to compression, emits a spark; the production of light-

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1088. How do they affect the needle? 1089. What is said of lightning?

ning is by some attributed to the same cause, viz: to the energetic condensation of the atmosphere before the electric fluid, in its rapid progress from point to point. When lightning is emitted near the earth, the flashes are of a brilliant white color; when the storm is higher, and therefore in a rarefied atmosphere, their color approaches to violet. (952.) Clouds appear to collect and retain electricity. When a cloud overcharged with electricity approaches another less charged, the electric fluid rushes from the former to the latter. In the same manner the electric fluid may pass from the clouds to the earth. In such cases, elevated objects, as trees, high buildings, church steeples, &c., often govern its direction. It is unnecessary to dwell upon the powerful and destructive effects of lightning.

1090. **Classes of lightning.**—Lightning has been divided by Arago into three classes, viz: zig-zag or chain lightning, sheet lightning, and ball lightning. This classification is convenient, and is universally adopted.

The form of zig-zag or chain lightning is supposed to be caused by the resistance of the air compressed before it. The lightning takes the path of least resistance; then moves forward until it meets with a like opposition, and so continues glancing from side to side until it meets the object it seeks. Sometimes the flashes divide into two, and sometimes into three branches; it is then called forked lightning.

Sheet lightning appears during a storm as a diffuse glow of light illuminating the borders of the clouds, and occasionally breaking out from the central part.

Heat lightning, as it is called, appears often in serene weather during summer, near the horizon; it is generally, if not always, unattended with thunder; heat lightning is the reflection in the atmosphere of lightning very remote, or not distinctly visible. By many, this phenomenon is supposed to be occasioned by the feeble play of electricity when the air is rarefied, and the pressure upon the clouds is so much diminished that the electric fluid cannot accumulate upon their surface beyond a certain point, and escapes in noiseless flashes to the earth.

Ball lightning appears in the form of globular masses, sometimes remaining stationary, often moving slowly, and which in a little time explode with great violence. This form of lightning is of very rare occurrence, and philosophers have not as yet been able to account for it.

1090. How has Arago classified lightening? Describe the several sorts.

Volcanic lightning.—The clouds of dust, ashes, and vapor, that issue from active volcanoes, are often the scene of terrific lightning and thunder. Volcanic lightning is probably caused by rapid condensation of the vast volumes of heated vapor thrown into the air.

The rapidity of lightning of the first two classes is probably not less than two hundred and fifty thousand miles per second. Arago has demonstrated that the duration of a flash of lightning does not exceed the millionth part of a second. The waving trees illuminated at night by a single flash of lightning during a storm, appear motionless; the duration of the flash is so short, that, during its continuance, the trees have not sensibly moved.

1091. **Return stroke.**—When a highly charged thunder cloud approaches the earth, it induces the opposite kind of electricity upon the ground below, and repels that of the same kind. If the cloud is extended, and comes within striking distance of the earth, or of another cloud, a flash at one extremity is often followed by a flash at the other. This latter is called the return stroke, and sometimes is of such violence as to prove fatal, even at a distance of several miles from the point of the first discharge.

1092. **Thunder.**—As lightning passes through the air with amazing velocity, it leaves void a space behind it, into which the air rushes with a loud report; this is *thunder*.

The rolling of thunder is generally ascribed to the reverberation of the sound from clouds and adjacent mountains. It is also considered that as the lightning darts to a great distance with immense velocity, that thunder must be produced at every point along its course, and the sounds not reaching the ear at the same time that elapses between lightning and its thunder, we are enabled to calculate the distance of the former. Sound travels at the rate of eleven hundred and eighteen feet per second. If the thunder reaches our ear five seconds after the flash, the distance is about a mile.

1093. **Thunder storms** are most frequent and violent in the torrid zone. They decrease in frequency towards either pole. Thunder storms are more frequent in the summer than in the winter months, and after mid-day than in the morning. They are produced in the same manner as ordinary storms; but they differ from the last in the rapidity and extent of the condensation of the atmospheric vapor, and in the accumulation of electricity. Thunder storms are usually attended by an alteration in the di-

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1091. What is the return stroke? 1092. What is said of thunder? 1093. What is said of thunder storms? 1094. What is said of lightning rods?

rection of the wind. Of one hundred and sixteen thunder storms recorded in the Meteorological Register of the Connecticut Academy, ninety-nine were either preceded or followed by an alteration in the direction of the wind.

1094. **Lightning rods** were first introduced by Dr. Franklin. He was induced to recommend their adoption as a means of protection to buildings, from the effects of lightning, by observing that electricity could be quietly and gradually withdrawn from an excited surface by means of a good conductor, pointed at its extremity. (925.)

Lightning rods are ordinarily made of wrought iron; but copper is preferable, being a better conductor of electricity, and less easily corroded. The size of the rod, if of iron, should not be less than three-quarter inch in diameter. The upper extremity of the rod should be pointed. Three points is the usual number used in the U. S., but one is sufficient. The points should be tipped with silver, gold, or platinum, or copper gilded by electricity; these metals being unaffected by the air, which would corrode the copper or iron, and render them poorer conductors. The rod should be continuous from top to bottom, and securely fastened to the building. Glass or wooden insulators are often recommended, but when once wet by a shower, there is but little advantage in them over metallic supports. When there are surfaces of metal about the building, as gutters, pipes, &c., these should be connected with the conductor by strips of metal, as first recommended by Prof. Henry. The lower part of the rod, where it enters the ground, should be divided into two or three branches, and bent away from the building, penetrating so far below the surface of the earth as to reach water, or permanently moist soil.

1095. **Protective power.**—According to M. Charles, a lightning rod protects a space around it equal to twice its height above the building. Thus, if a conductor extend ten feet above the house, it affords protection to a circular space forty feet in diameter, the rod being in the centre.

Conductors do not attract the lightning toward the building upon which they are placed. They simply direct the course and facilitate the passage of the electricity to the earth, which otherwise might have been effected in a powerful and destructive discharge through the building. It is indeed considered by Arago, that "lightning rods not only render strokes of lightning inoffensive, but considerably diminish the chances of a building being struck at all."

1095. How is the protective power of lightning rods estimated?

ERRATA.

Page 9, line 4, for "not fluid," read, not void.

Page 15, last line, for "is electricity?" read, is elasticity?

Page 21, line 15, for æriform, read, aeriform. This misprint occurs also on pages 198, and 371.

Page 101, last line, for $v=g\sqrt{\frac{s}{g}}=\sqrt{4g^2}$, read, $v=2g\sqrt{\frac{s}{g}}=\sqrt{4gs}$.

Page 105, line 18, for "; that is, *a c*," read, ; that is, *a e*.

Page 131, line 22, for "$P \times AF\ BF\ CF = W\ DF\ CF\ BF$," read $P \times AF \times BF \times CF' = W \times DF' \times CF \times BF$.

Page 202, line 1, for "Madgeburgh," read, Magdeburg.

Page 257, line 7, for "altitude of the wave," read, amplitude of the wave.

Page 262, line 26, for "again at *c p*;" read, again at *C*.

Page 279, line 23, for "of continuous vibration, rapid and isochronous," read, equal atmospheric vibrations.

Page 279, line 24, for "a prolonged sensation," read, an unvarying sensation.

Page 279, line 33 and 34, for "in order to produce them there must be quick vibrations, which are," read, although the wave may be slow, it is.

Page 283, line 5, for "211," read $213\frac{1}{3}$.

Page 284, line 38, for "between the sounds," read, between five sounds.

Page 285, line 6, for "between all notes," read, between five notes.

Page 285, line 31, for "or $\frac{5}{8}$, read, or $\frac{4}{5}$.

Page 293, line 17, for ", *d d*," read, , *a a*

Page 304, line 33, for "Rumford (1805), read Rumford (1798.)

Page 310, line 31, for ", and 90 × 32, read, and 90 + 32

Page 329, 5th line of questions, for "sometimes used," read, sometimes deranged by heat.

Page 336, 11th line of table, for "312°," read, 212°.

Page 340, 4th line for "$V = (1 \times$," read, $V = 1 +$.

Page 340, line 10th, for $=\frac{v}{491}+T$, read, $=\frac{v}{491}\times T$.

Page 341, line 10th, for $\frac{T}{T'}+\frac{P'}{P}$, read, $\frac{T}{T'}\times\frac{P'}{P}$.

Page 353, line 20th, for "arithmetical progression," read, geometrical progression.

Page 374, line 28, for "of 130° and 146° F., read, "of —130° and —146° F.

Page 395, line 11, for "Liebeg's," read, Liebig's.

Page 414, line 17, for "Otto and Guerick's," read, Otto von Guerick's.

Page 424, line 22, for " carbonic acid driven," read, carbonic acid derived.

Page 477, line 21, for *Kalycromatics*," read *Kalychromatics*.

Page 540, line 27, for " a grain," read, a gramme.

Page 568, line 10, for " after '*electricity*' add," read, 5th Life.

Page 573, line 27, for " natural elasticity," read, natural electricity.

Page 588, line 38, for " in 1755," read, in 1785.

Page 624, line 31, for " 980," read, 981.

Page 663, line 25, for " Mognio," read, Moigno.

The following cuts were inverted in the printing, 59, 86, 401.

[N. B. The reader is requested to insert these corrections with his pencil in their proper places.]

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[THE REFERENCES ARE TO SECTIONS, NOT TO PAGES.]

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